Author: Valentina Petri
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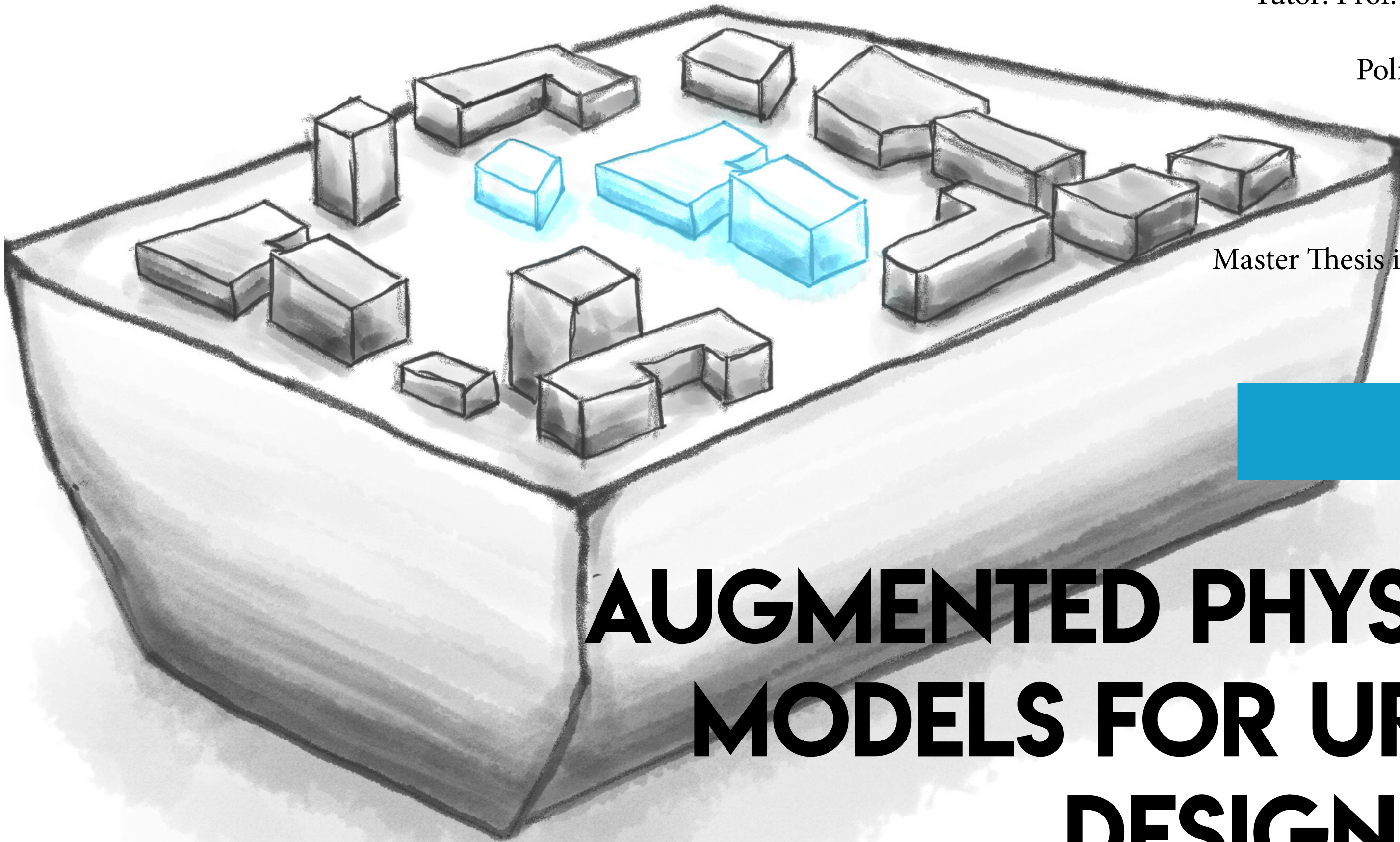
Politecnico di Milano
A.A. 2016 - 2017



Master Thesis in Urban Planning and Policy Design

AUGMENTED PHYSICAL MODELS FOR URBAN DESIGN AND PLANNING

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and Policy Design

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Matr. n° 822730

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“L’uso del plastico del progetto, attraverso gli strumenti di simulazione consente di vedere gli effetti generati, quindi di aggiustare e migliorare il progetto nel corso dell’apprendimento…

…Utile strumento per simulare gli effetti generati dai progetti sul contesto e per migliorarne quindi l’adattamento al contesto, facilitando sia negoziati trasparenti tra i diversi soggetti in gioco, sia una partecipazione consapevole della cittadinanza mostrando gli effetti generati, sia anche cercando di capire gli effetti ambientali sul comfort urbano, sugli spazi pubblici, gli effetti sonori, e gli effetti di complessiva qualità ambientale che il progetto inserito nel contesto produce.”

Fausto Curti

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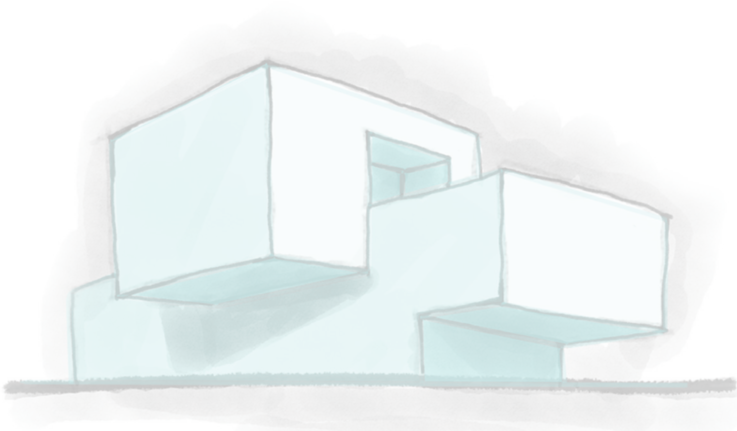

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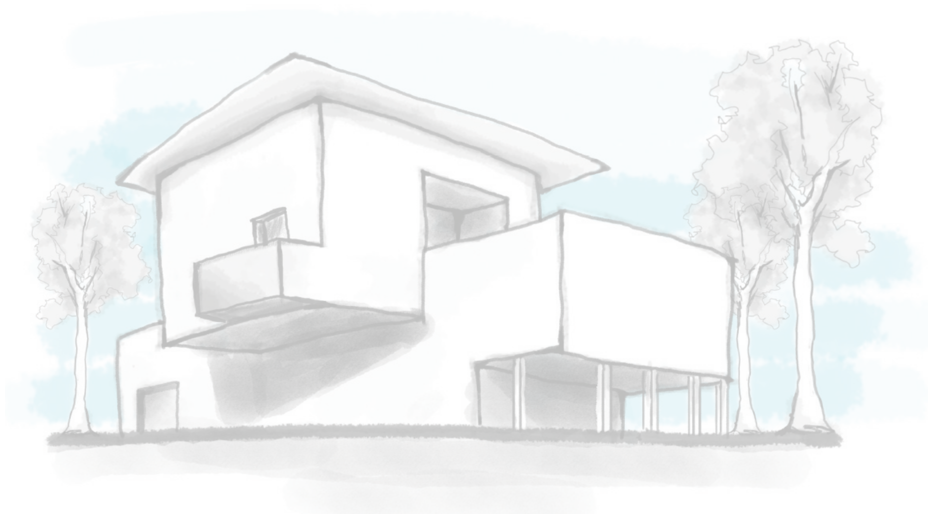
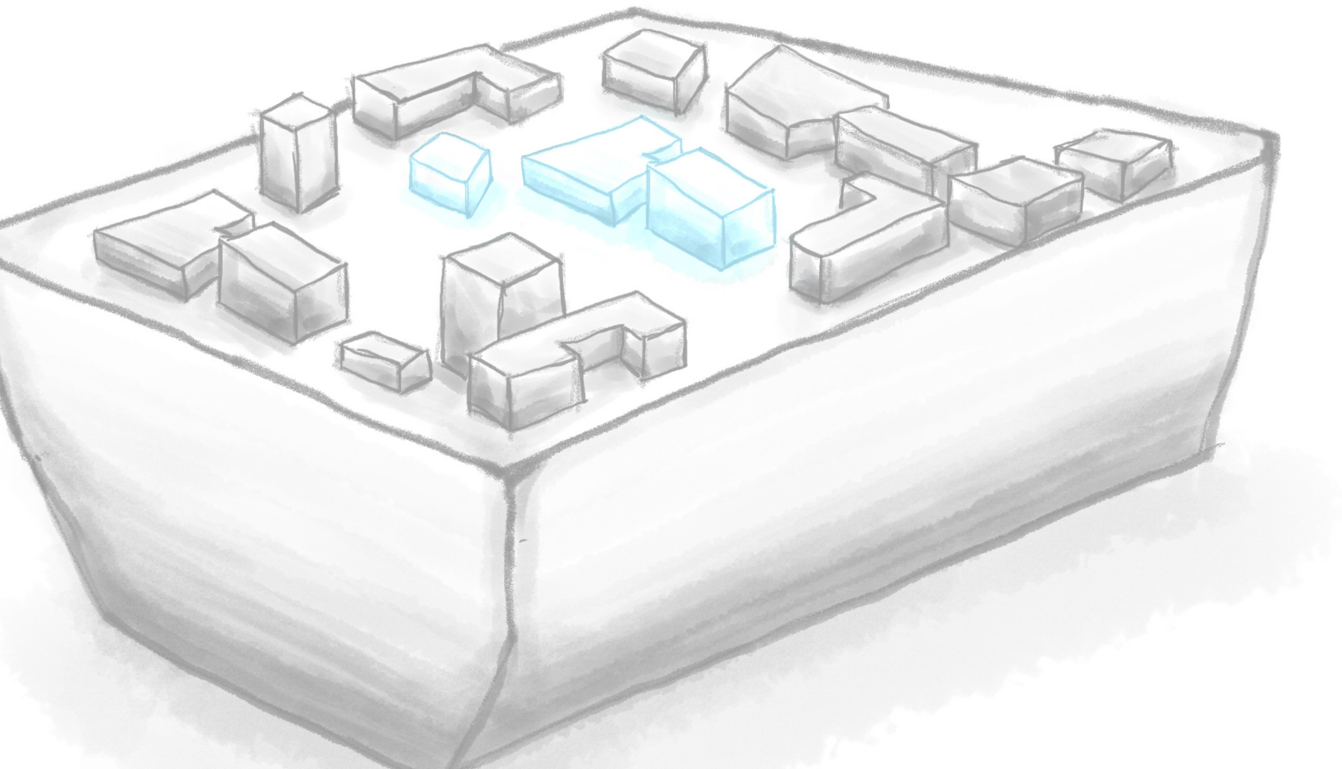




ABSTRACT

KEYWORDS: Level of Details, Maquette, Physical model, Digital model, Urban Simulation, Augmented-Reality, Mixed-Reality

The thesis investigates Augmented Reality for scaled models for urban planning and it proposes a novel method based on the reframing of the Level of Details for Augmented Physical Models. In particular, the research analyzes the possible integration between physical and digital models, through solutions such as Augmented Reality (AR). The goal is to investigate which level of detail (LOD level of details) is required for merging physical and digital models in order to take advantage of the mixed solutions. The method is developed for models at different scale, i.e. from landscape (1:10000) to architectural models (< 1:50).

More in detail, the thesis studies the state of art of the subject, proposes a theoretical framework and an application method; in particular, the initial part of the thesis presents a survey of bibliography and significant case studies; the central part develops a reference method for the case of applications and illustrates the application of the method on specific cases. The ultimate goal is to return a picture of the possibilities guaranteed by existing technologies and to develop an hypothesis about future applications for urban planning. The research outcomes can inform different application in the professional field, such as public participation, evaluation and decision-making and training.

Questa tesi presenta un lavoro di ricerca sulla Realtà Aumentata applicata ai plastici in scala per la pianificazione e l'urban design. In particolare, propone un nuovo metodo di inquadramento sui livelli di dettaglio specifici per i modelli in scala; inoltre, viene approfondita la possibile integrazione tra modelli fisici e digitali, attraverso strumenti quali la Realtà Aumentata (AR). L'obiettivo è quello di indagare quale livello di dettaglio (level of details LOD) fisico e digitale è necessario per fruire di queste soluzioni miste. Il metodo sviluppato per modelli fisici con diverse scale di rappresentazione, dal paesaggio (1:10000) ai modelli architettonici (< 1:50).
In particolare, la tesi studia lo stato d'arte, propone un quadro teorico di riferimento e una proposta di metodo applicativo; più in dettaglio, la tesi esamina lo stato dell'arte del soggetto, propone un quadro teorico e un metodo di applicazione; in particolare, la parte iniziale della tesi presenta un sondaggio di bibliografia e significativi casi di studio; la seconda parte sviluppa un metodo di riferimento per il caso delle applicazioni e illustra l'applicazione del metodo su casi specifici.

L'obiettivo finale è quello di ripristinare un'immagine del potenziale delle tecnologie esistenti e di sviluppare un'ipotesi sulle future applicazioni di pianificazione urbana. I risultati della ricerca possono informare diverse applicazioni nel settore professionale, come la partecipazione del pubblico, la valutazione, il processo decisionale e la formazione.

INTRODUCTION

RESEARCH QUESTION

To facilitate visual communication of urban projects through emerging technologies, an analysis on the tools available nowadays - and those that we can envision for the future - is needed. For this reason, the thesis will answer at this main question:
Is it possible to codify the relationships between physical and digital models level of details in order to optimize a combined use (augmented models)?

The ultimate goal is to demonstrate that the proposed method and approach can support the design and evaluation processes of urban transformation, and increase their effectiveness.

The text is divided into three main parts: (i) *The Research Context*: the root of the thesis that refers to relevant authors, key concepts and presents the study of some relevant case studies. This specific chapter provides an explanation about the process followed during the project and finally highlights reasons why some aspects related to the latter are significant references. In conclusion the text addresses the analysis and the study of the state of art regarding Level of Details in relation to 3D digital model context. (ii) *Augmented Maquette*: the chapter includes the final considerations of the study developed on Levels of Details. ll the information emerged from the research context are here collected and merged in a unique result, that is the definition of new level of details for Augmented Scale Models (AR); last chapter presents a study on the needed tools for this kind of mixed-solution, in particular apps designed for AR that can be adapted for augmenting physical models. (iii) *Conclusions*: last chapter introduces some possible future scenarios through the application of new technologies for urban planning and design.

PART ONE

RESEARCH CONTEXT

01

PHYSICAL AND DIGITAL URBAN SIMULATIONS

This first chapter provides a general overview of the key topics discussed in this thesis, thus providing an introduction to the state of art of the three subjects and thus to clarify basic concepts of the thesis. First, general considerations on (i) *Urban Simulations* on their utility and function, further deepening talking about the (ii) physical model (or will be appointed as maquette) as a support tool for experiencial simulations; hence, a section dedicated to another key element of the argument, that is related to (iii) *Virtual Reality* and *Augmented Reality;* the function of this chapter will therefore be to provide an adequate introduction to basic concepts that will make up the thesis.
Make possible to codify relationships between physical models and digital models in terms of level of details, in order to optimize a combined use though Augmented Reality, will be the purpose of the next chapter.

Description of a method of the comparative analysis between definition of level of details and characteristics of digital models, who defined them, how they have been modified according with new considerations, will provide a reference method for the case of applications.

1.1 URBAN SIMULATIONS

Urban Simulations, in particular perceptual and experiential simulations - intended as a replication of physical environments (also with their own atmosphere) - though a technical device, can help to illustrate urban issues linked to urban design and planning (Piga E.A.B.. et al. 2015). The presentation of design proposals, plans, or design projects to the public, or to public representatives, often involves communication to the lay audience, and simulations can be the bridge between them and the proponents.

The simulation can work together in order to show how the urban transformations impact on the urban experience from, at least, the visual perception point of view; an example would be how the geometric proportions change if we change the point of view, or the perception of materials, or details are influenced by light.

This is a useful method in order to anticipate different outcomes at the same time in one place.

The visual aid given by the images to verbal communication encourages attention control and participation as well as make communication clearer and more effective.

The immediacy of the simulations also reduces interpretation time, a difficult process both for experts and for lay people to deal with this type of analysis, thus making it easier to decode and re-elaboration of the concepts. Therefore it is necessary to propose accurate visual content with presentations from the optimal timing to keep alive the attention of users.

The simulation can be a useful reference for the presentation of projects, for example to highlight specific features. Its ability to make evident the perception of the environments makes it an important tool in communications dealing with the physical aspects of urbanism. It helps in visualization of the different impact of different design concepts, because they could be compared in order to highlight a number of specific conditions, including shading or wind.

It’s important to understand that a simulation, if not properly carried out, it could distort the perception of an environment. It is therefore necessary to develop a critical attitude, through the comparison between the various types of simulations to verify the reliability.

“In order to carry out a good simulations, they should be realistic and accurate; that is, they should convey how a project will be experienced. They should be *comprehensible* and *evaluatable*; people of all educational levels should be able to understand them and they should be able to evaluate them on the basis of their own concerns. Simulations should be *engaging*: they should not bore an audience so that they miss valuable information; and finally they should be *flexible*.” (D.Appleyard, 1977)

1.2 MAQUETTE

In this paragraph, several reasons that make physical model an effective simulation of reality are illustrated, and also many are the reasons why we still investing this tool. Usually, this kind of instrument is designed with the purpose of provide a “cognitive map” and the spacial relationship between buildings and the environment(Michael J O’Neil, 1991).
What distinguishes it, is the fact that it is truly *three-dimensional.* This implies the decision to the scale first, and therefore a limitation on its level of detail. In the moment in which is produced a perceptual simulation, the detail is perceived regardless of the scale. However, if the definition of the details is minimal, the final result will not be exhaustive enough.

With the decrease of the *scale*, also increases the possibility of adding details, at the level of architectural finishes and some elements of context, such as the street furniture. It is therefore important to define the correct scale, weigh every item that will affect both the understanding of the project both on the final

Fig. 1.1 Architectural models | TOP: Varesine ville di porta nuova; BOTTOM: Opificio via Magolfa | copyright ONEOFF

size that the plastic should have; including the portion of the context, the opportunity to interact with the elements, the ability to see in a single glance the modeled area as a whole.

The *immediacy* makes the maquette ideal for communicating with a non-expert public. The way you can interact with a maquette makes it a key point for public involvement that can interact directly, even in moving their own parts of the model, able to contemplate some details etc. (Piga E.A.B, 2010)

Maquette (Fig. 1.1) is an highly interactive tool, in fact, the user can choose which point of view to take, to have a bird's eye view of the entire portion of the city concerned and size what are the relationships between the various urban elements. This remains within the *conceptual perception* (Morello E. et al. 2015); therefore when the level of detail of the textures and finishes increases, the perception becomes even perceptive.

In addition, the maquette allows interaction not only individually, but can represent a key tool for a discussion between a more or less large group of people, who can then interact with the maquette and its entirety, think about the project and realize a better debate. Another type of simulation which is always used is of analytical type with regard to the area of the project shading via *Heliodon* (Podestà, 2017)*,* a sun emulator that acts directly on the physical model, which accurately demonstrates the motion of the sun and allows an accurate shadow study, and the trend of the winds thanks to the *wind tunnel* as well.

One limitation of the maquette, is in the handling of some dynamic elements, including cars and people that were otherwise feasible using digital modeling and Virtual Reality. The solution to overcome this limit, beyond the post-production, the use of **Augmented Reality** in real time; through the use of apps and other instruments, such as SmartGlass, it makes possible the implementation of certain details within the preliminary model, in order to increase its level of detail in real time.

1 . 3 VIRTUAL, AUGMENTED AND MIXED REALITIES

At this point, is necessary to provide some definitions of *Virtual Reality and Augmented Reality*, and when they were born. During 60s, Professor Ivan E. Sutherland (1963) started to develop the “Sketchpad” (Fig 1.2), a display for a graphical communication; after few years he constructed a viewer capable of showing 3D images that overlap with real objects, making it essentially the first example in history augmented reality.

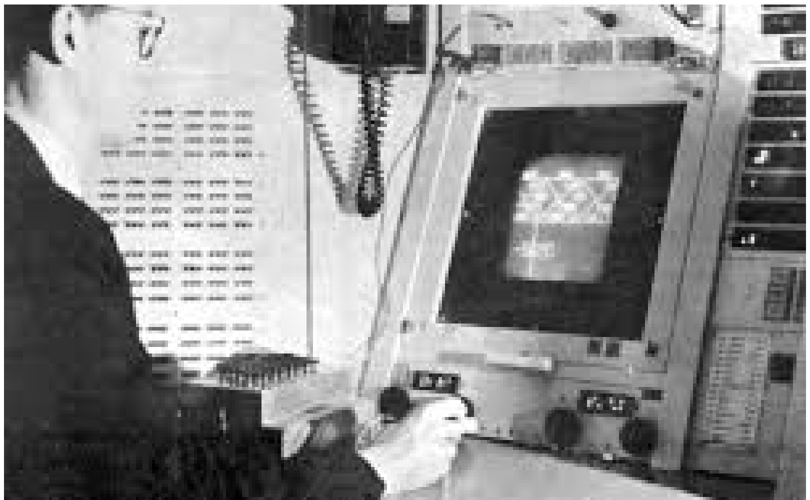


Fig 1.2 *Sketchpad* created by Ivan E. Sutherland | 1963

At this point, is necessary to provide some definitions of *Virtual Reality and Augmented Reality*, and when they were born. During 60s, Professor Ivan E. Sutherland (1963) started to develop the “Sketchpad”, a display for a graphical communication; after few years he constructed a viewer capable of showing 3D images that overlap with real objects, making it essentially the first example in history augmented reality.

During the years, many people have given different definitions of virtual and augmented reality. Following some relevant interpretations of Virtual, Augmented and Mixed realities are indicated; for instance, Daniela Bertol defined Virtual reality as:

> “*Virtual reality is a computer-generated world involving one or more human senses and generated in real-time by the participant’s actions. Augmented reality merges the virtual reality world with the real, actual environment; an augmented reality application complements the real world perception with information not ordinary discernible by human senses”* (Designing Digital Space, Daniela Bertol 1997)

Ronald Azuma, Senior researcher staff computer scientist, gave his interpretation of Augmented Reality (AR) as:

> *“is a live, direct or indirect, view of a physical, real-world environment whose elements are augmented by computer-generated sensory input such as sound, video, graphics or GPS data.”* (Azuma, ACM SIGGRAPH 2004, Article No. 26).

The concepts that can be extrapolated from the above definitions, may be summarized into 3 main points:

- combines real and virtual objects in a real environment;
- registers (aligns) real and virtual objects with each other;
- runs interactively, in three dimensions, and in real time.

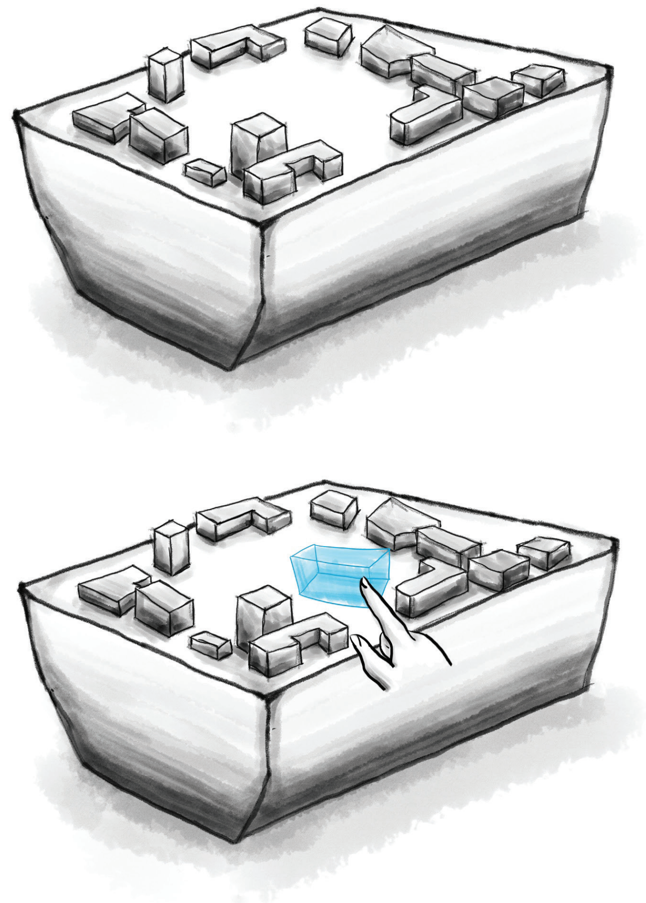
Trying to summarize what has been said, they can be resume in this way:

Ideally example of
Augmented Reality | (idxitaly.com)

Fig. 1.2 concept of augmented reality applied on physical model | copyright the author

AUGMENTED REALITY

OVERLAPPING OF 3D OBJECTS WITH THE REAL WORLD THANKS TO DIFFERENT DEVICES



Virtual Reality (VR) was born from the will to "replicate" the reality, as precisely as possible, for making actions in the virtual space. The direct interaction with the scenarios can turning a three-dimensional object on a monitor via the mouse or manipulating it in an immersive environment.

Augmented Reality (AR) means the enrichment of human sensory perception by means of information, usually manipulated and conveyed electronically, that would not be perceived with the five senses. It happens through the overlapping of 3D objects with the real world thanks to different devices. (Fig.1.3)

However, the article that has been the milestone of taxonomy of Augmented Reality,written by Milgram and Kishino (1994), which is one part of the general area of mixed reality. Both virtual environments (or virtual reality) and augmented virtuality, in which real objects are added to virtual ones, replace the surrounding environment by a virtual one. In contrast, AR takes place in the real world.

Mixed Reality (MR) is defined (Paul Milgram, Fumio Kishino, 1994) "*anywhere between the extrema of the virtuality continuum (Fig.1.3), where the virtuality continuum extends from the completely real through to the completely virtual environment with augmented reality and augmented virtuality ranging between.*"

This continuum is one of the two axes in Steve Mann's concept of mediated reality (refers to the ability to add to, subtract information from, or otherwise manipulate one's perception of reality through the use of a device), researcher and inventor of many wearable computing starting from the 80's.

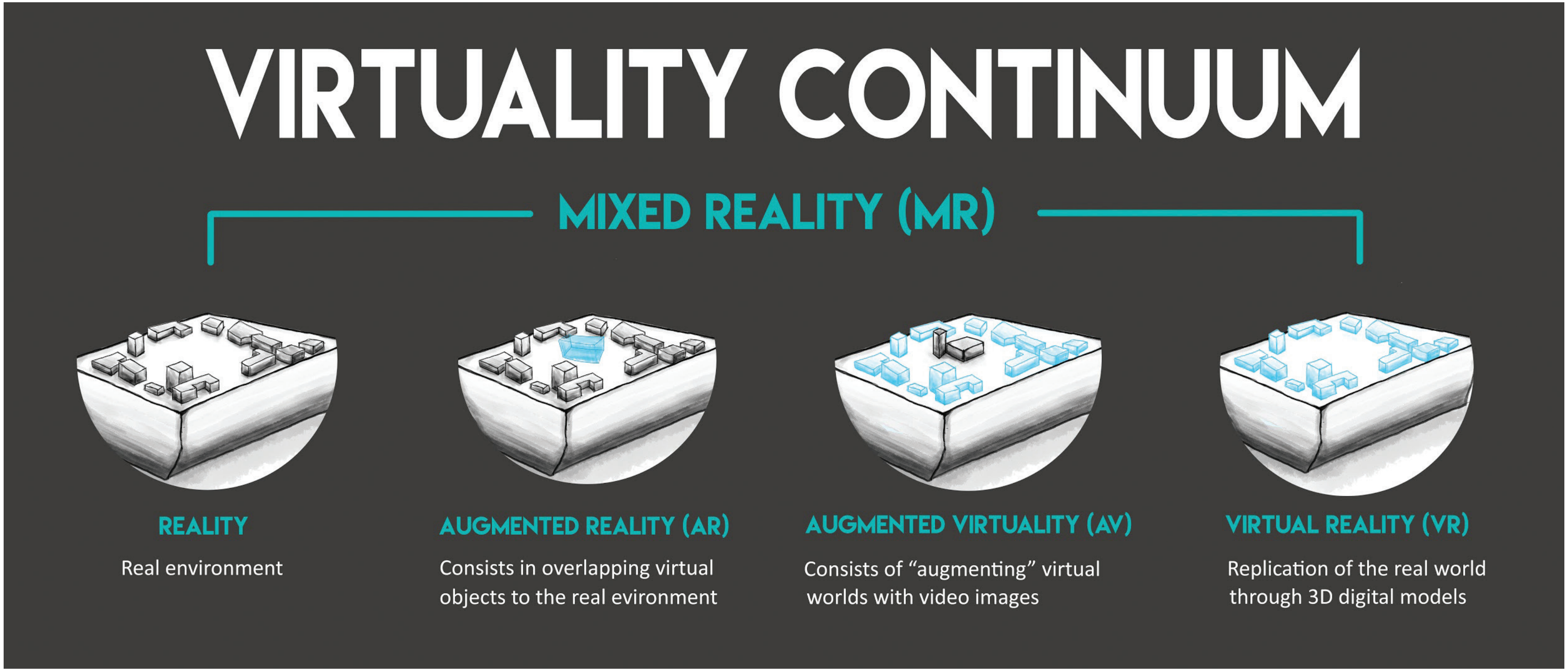
The fundamental difference between Augmented Reality and Virtual is given by the simulation concept that is used. Virtual reality lead us through a system more or less an immersive, tricking our senses; Augmented Reality (AR), in contrast, adds information levels with different nature to our perception.

A very interesting example that prove how versatile MR is, the University of Central Florida provided an example reskinning the interior of a museum to better engage visitors with the exhibits; In the MR Sea Creatures experience in the Orlando Science Center, visitors saw the museum interior transformed to be underneath the sea, and skeletons of ancient sea creatures on display then came to life (Azuma, 2015).

In a nutshell it comes to a perceptual enhancement, based mainly on the *generation of virtual content from a computer and from their overlapping with reality.* It 's important to point out that these integrations are not limited to visual data but they can understand, if the technology allows it, olfactory data, auditory and even tactile. This introduction gives a general overview about main subject of this Thesis: *urban simulations*, their applications for urban design and decision making; the *physical maquette* which is still a fundamental tool due to create effective urban simulations and *Augmented Reality*, the new technology used by various devices applied in different fields.

These three elements settles the base for the **Augmented Maquette.** The next step shows many representative case studies related to projects, technologies, devices and application which involved in some way physical models, augmented reality concepts ect.

Fig 1.4 *Virtuality Continuum* | Source: Paul Milgram, Fumio Kishino, 1994 | concept which was expressed by Milgram and Kishino about virtuality continuum is configured | Image copyright: the Author



02

CASE STUDIES ANALYSIS

In the following paragraphs, we will analyze several case studies, each with its scientific importance, in order to show how different urban simulations, applied in different ways and technologies, bring into prominence some decisive aspects in this thesis. There will be shown six cases, with different features, natures and configurations, but useful to understand some different approaches related to what is written in the previous chapter about main elements. Each of them are described through: (i) an *introduction* to the singular case, who is the creator and curator ect..; (ii) the *process*, so how the project works and which are the purposes; (iii) *what is relevant* for the thesis, the reason why some aspects related to the project are significant references.

2.1

“MACHIDUKURI”: CREATING COMMUNITY WITH VISUAL SIMULATION

SHIGERU SATO

Introduction: Professor Shigeru Sato from Tokyo University of Science was the creator of what is called *Machizukuri* (in japanese) after 80s that means “community building” or “community planning” in english, a process to facilitate the collaborative urban regeneration (Fig 2.1).

He did a process for create the community of inhabitants without a specific knowledge starts with a series of workshops named “design Machidukuri game” where people around architectural models, through the simulation of existing conditions, defines some guidelines that finally are adopted and followed by residents. (Masahide H. 2009)

Process: Most important for people’s daily life is the understanding what a community will look like and how living there will effect human experience.

For example, residents are interested in how changes might effect shades on private properties, how the solar access patterns on the streets how shades change in summer and winter ect... Through visual simulation is possible to show these effects, in order to allow residents, who are not specialists, to visualize how such changes will effect their lives. They can build consensus.

The system: CCD (charge coupled process) camera with Wide & Telephoto lens, looking at 1:100 or 1:200 models, where the camera moves automatically and can look in different directions.

What is relevant: In the field of urban planning, the idea of citizen inclusion in the design process is becoming increasingly rooted. The concept itself of community building, *including citizens directly in the project, making them part of the changes in their neighborhood, where they live everyday, making them aware of the process*, represents the key aspect of this project. The *Augmented Maquette*’s purpose is to become an important support tool in a future scenario, playing the same role of this project, which shows how much is necessary to include people in the process in order to keep in mind the main goal, design thinking about who is dedicated to the project, to the needs of those who will live there; public participation is fundamental for a good plan.

2.2

HYPER-REALITY: VISION OF THE FUTURE

KEIICHI MATSUDA (2013)

Introduction: “Hyper-Reality is a concept film by Keiichi Matsuda. It presents a provocative and kaleidoscopic new vision of the future, where physical and virtual realities have merged, and the city is saturated in media. It is the latest work in an ongoing research-by-design project by Keiichi Matsuda.”

Process: Nowaday, our physical and virtual realities are becoming increasingly interconnected with many technologies such as VR, AR, wearables, and the internet of things which are pointing to a world where technology will envelop every aspect of our lives. It will be the glue between every interaction and experience, offering amazing possibilities, while also controlling the way we understand the world. With *Hyper-Reality*, the videomaker Keiichi Matsuda is trying to explore this trajectory that technology is making, in a sort of provocative way such as a super-futuristic view of the city. The chosen location was the city of Medellín, Colombia. In the first picture (Fig.2.2) there are a couple of samples taken from Matsuda’s Hyper-Reality video; the overlapping of digital elements is very strong and overloaded the urban imagery.

Fig 2.2 | *screenshots video "Hyper - reality"*
Link: https://vimeo.com/166807261

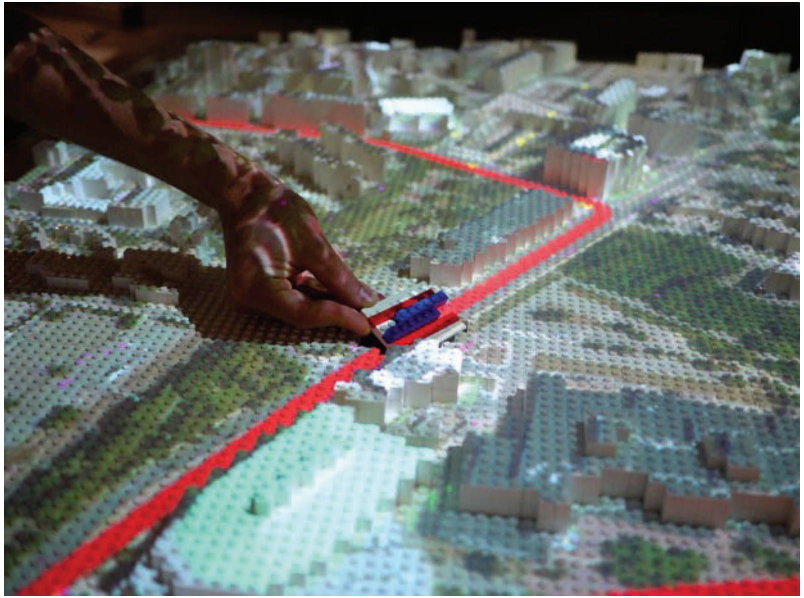
Fig 2.3 | *Screenshots video "Hyper - reality" (min 5.13) | UP Hyper-reality overlying the city; DOWN the real environment from the same perspective*

The other picture (Fig.2.3) shows differences between the Hyper-reality imagery and the real environment from the same point of view, in order to better understand which is the real impact you get on it.

What is relevant:
Certainly, this type of project as already mentioned, is very provocative and to the limit achievable. The genius Matsuda shows a hypothetical future scenario, where the digital and the real overlap constantly; but this is precisely the what makes this project relevant in this thesis, the use of AR to transmit and show directly in a visible way, hidden and implicit information. With the new proposal, the author will think about what kind of digital information may overlap the real environment, and also by what methods, such as geolocation of information, markers, etc...

(Web: http://hyper-reality.co)

Fig 2.4 | *MIT's new tools allow users to literally play with transit-planning concepts. (MIT Mobility Futures Collaborative/Media Lab Changing Places Group)*



2.3

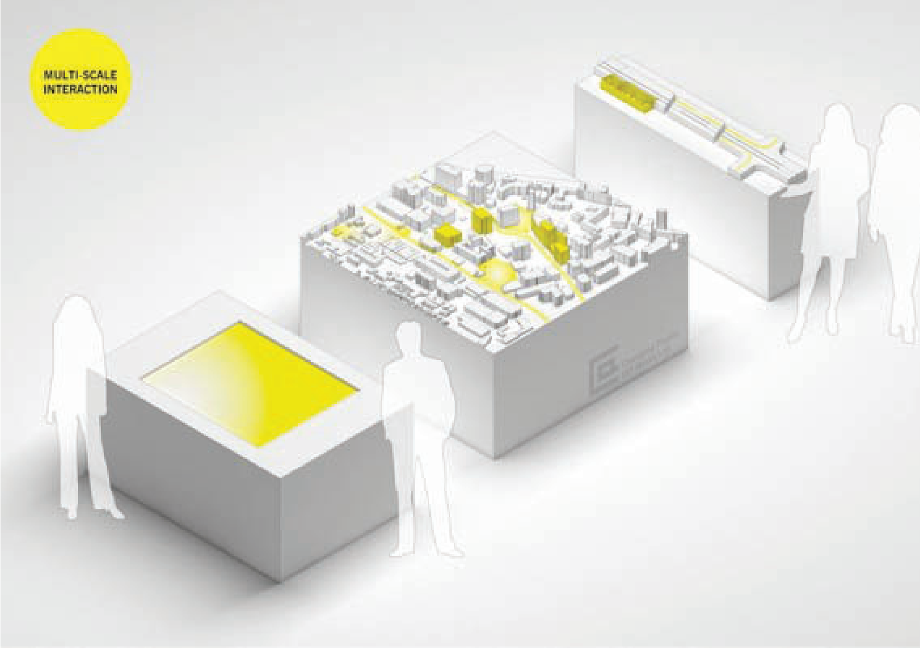
LEGO: UNEXPECTED URBAN PLANNING TOOL

MIT: LINDA POON (OCTOBER 2015)

Introduction: Researchers belonging to the MIT Media Lab of the Department of Urban Studies and Planning in Boston, published an article "Using Legos as a Legitimate Urban Planning Tool", which sets out one of their projects to involve both children and planners professionals alike, creating an interactive Dudley Square maquette, where streets, people, sidewalks, bus stations and buildings are constructed entirely of LEGO.(Fig 2.4)

Fig 2.5 | *An example of a Boston's street made up with LEGO* | Official MIT Website (visited December 2016)

Fig 2.6 | *Three components which represent a portion of Boston in two different scales plus a touch interactive screen* | Official MIT



Process: The use of this project was meant to test how the new fast bus transportation systems would influence the city. The test comprises three different components (Fig. 2.6) , each of which represents the city of Boston in two different scales. A model in Lego Dudley Square, a second 3D model also in Lego of a street in Boston (Fig. 2.5), and finally an interactive touchscreen to illustrate how the upgrades will be carried out at regional level to affect the transit of public transport, and then accessibility of people to jobs.

Models were available for the public, which was free to explore and see how their lives and habits could benefit or suffer after the changes made to the transport network; via the touch screen could select some parts of the city, in order to look more closely at the changes. Lego on the two components could instead move the bus in order to witness how the traffic flows would change, projected directly on the model itself.

The goal of this test was to make the process more transparent urban planning in order to get everyone involved, not only experts

"Part of our idea with the introduction of such tools is to break away from the technocratic model of planning. The platform lowers the threshold for participation, because every child knows how to move a piece of Lego. The interactivity has allowed users to see these changes, to play with, and to comply with estimates of what would be the cost of these changes. our ultimate goal is this idea of co-creation"

What is relevant*:* A physical model made by LEGOs could only be considered as a toy, but it really has a huge potential, especially if you go to communicate with a diverse audience. Also *a guided interactive model, can be a key element in the communication of a project, especially when it comes in contact with a non-specialized users,* as in this case children.

The Augmented Maquette wants to be an interactive tool as this project is, where everyone, students, inhabitants, children, professionists and so on can interact at the same time with a physical object; it is still difficult approaching citizens or people with no knowledge of certain types of technology, but with the technological generation in the future scenario it is supposed to be much easier.

http://www.citylab.com/tech/2015/10/legos-as-a-legitimate-urban-planning-tool/410608/ (visited December 2016)

2.4

"TAVOLO LUMINOSO": THE LUMINOUS PLANNING TABLE

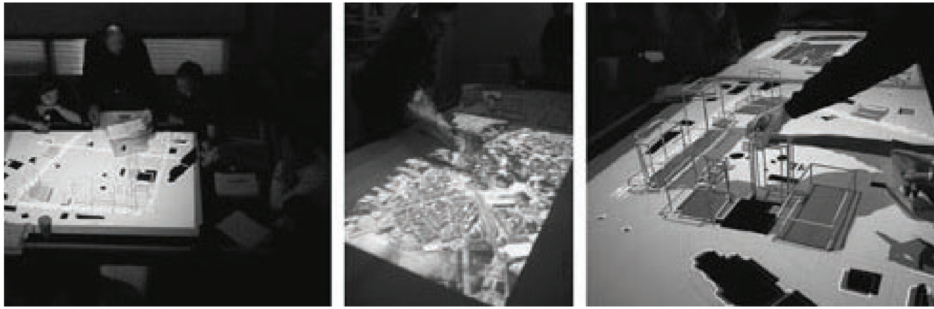
LABSIMURB: LAURA CIBIEN (2010)

Introduction: Keeping to speak about MIT (Massachusetts Institute of Technology), the MediaLab and the School of Architecture and Planning in 1999 created a prototype of The Luminous Planning Table (Fig.2.7) which is defined as a Tangible User Interface (TUI):

" It is for 2D and 3D physical and digital representations on several levels. Drawings, sketches, maps, satellite photos, and physical model, at the samescale, can be overlapped creating an hybrid space with various information that could enrich the urban planning process.

The aim is to provide physical planners and urban designers with an interface to communicate their spatial concepts and ideas to a broader public." (L.Cibien, *Urban design and representation* 2017)

Fig 2.7 | Lumionous planning table MIT (2001)



Process: The user is able to physically models its work with a direct interaction with the tool, helping itself to understand the meaning of the spaces involved in the project. The elements placed on the table can be handled with ease, allowing everyone, from citizens not specialized to professionists to participate in the process.

[...]"The ergonomics of the table allowed the working group to work simultaneously on the project, helping the dialogue and the creation of shared ideas. The large physical size of the LPT enabled participants to engage together in the design process." [...] (L.Cibien, *Urban design and representation* 2017)

In 2010 at Laboratorio di Simulazione Urbana Fausto Curti, two PhD students Laura Cibien and Francesco Secchi developed a prototype of Tavolo Luminoso (Fig.2); the aim of the project was to create an interactive tool for 2D and 3D workable models, which has to be flexible, interactive, and user friendly.

[...] "Investigate the availability of software developed to link real and digital objects,
preferably with a graphic user interfaces ease to use, freeware licenses, and with
access to the source code. Build a physical interface suitable for 3D models and on which to project digital content, large enough to allow multiple users to collaborate, but to be easily portable. Create a touch screen large as the whole interface to allow users to bypass the need for a PC while interacting with the digital content." [...] (L.Cibien, *Urban design and representation* 2017)

What is relevant: This represents another important example of urban simulation conducted through the *combination of physical objects, like scaled model's elements, and digital feature*; the LPT is indeed, a typology of augmented reality tools, but with a different behavior. Is closely related to the concept of the augmented maquette explained in this thesis, because in a sense they belong to the "same family" of simulations. The Urban Simulation Laboratory in Politecnico di Milano in fact has as one of the main focus the research in AR field

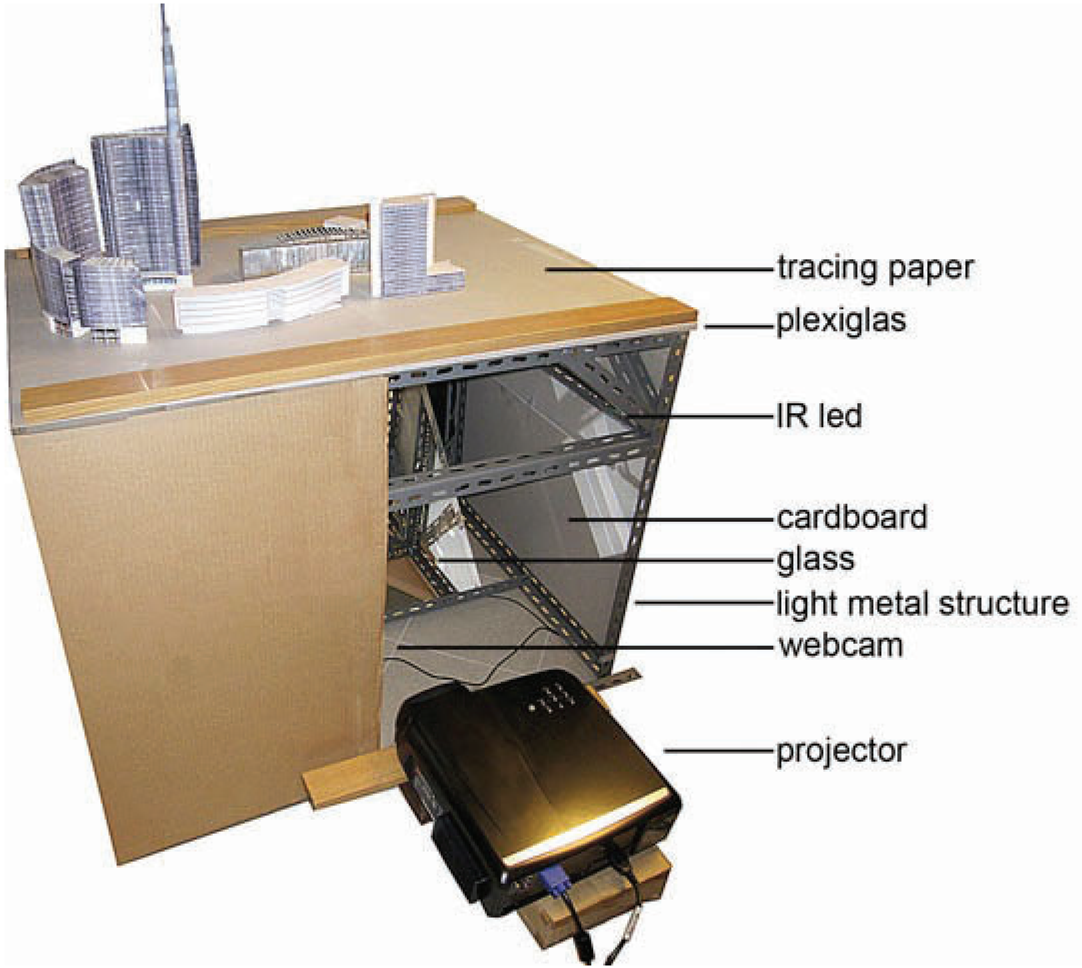


Fig 2.8 | Tavolo luminoso with its components created at Laboratory of urban simulations in Politecnico di Milano (2010)

2.5

A TOUR INSIDE PHYSICAL MODEL: GERIBALDI-REPUBBLICA PROJECT

URBAN SIMULATION LABORATORY
POLITECNICO DI MILANO (2007)

Introduction: The Porta Nuova project was one of the most relevant in the city of Milan. The Laboratorio di simulazione urbana Fausto Curti makes project’s evaluation, and supports different kind of urban simulations in order to study changes and impacts of new projects on the urban environment.

Process: The maquette 1: 500 (Fig. 2.9) helping the understanding of the project in its proportions, and relation between buildings; and the cognitive support closer to the physical reality, which enables a single glance, to understand the set.

Fig 2.9 | Laboratorio di simulazione urbana Fausto Curti | on the right: 1:500 physical maquette of Garibaldi Repubblica

Fig 2.10 | *Microcar by BETANIT with endoscopic camera filming inside the maquette from a subjective point of view*

Simultaneous use of the physical model, the 3D dimensional support and filming inside the model through a microcar (Fig. 2) designed by Betanit, provides an excellent tool that allows you to have an immediate reference to the views vision of the whole. A technique used was the result of the superposition of a photomontage recovery of the existing and render obtained from the 3D digital model. The final outcome of the project was a video with the subjective view inside the physical model, simulating a tour inside the physical city.

What is relevant: This project includes the use of many tools (analog and digital) on a specific detailed maquette, in order to create different multisensory simulations. This is a good example because shows how different instruments in urban evaluations can cooperate, as the augmented maquette want to reach, combining a scaled model and the augmented reality. Also, another thing that makes this example significant for the argument, is the typology of physical model which is used for this simulation; it laids in a specific category of mockup that fit Augmented Maquette standards which the author will define inside part 2 of the text.

2.6

THE COLLABORATIVE DESIGN PLATFORM

CDP REASEARCH GROUP OF TECHNISCHE UNIVERSITÄT MÜNCHEN

Introduction: Following the previous case, a research group of Technische Universität München create the collaborative design platform:

"The motivation behind the CDP interdisciplinary research project is to resolve the current discrepancy between familiar, analogue ways of working in the early architectural design stages and the ever increasing use of digital tools in office practice. The project's objective is the conception and prototypical realisation of an interactive work environment for use in the early design phases. By directly linking familiar analogue ways of working with digital computer aided design tools, the CDP represents a working environment that allows designers to work the way they are used to while making use of the potential of computers." Head of the CDP Research Group Dr. - Ing. Gerhard Schubert

Process: Presentations and discussions between architects and clients during the early stages of design usually involve sketches, paper and models, with digital information in the form of simulations and analyses used to assess variants and underpin arguments. Laypeople, however, are not used to reading plans or models and find it difficult to relate digital representations to the real world. Immersive environments represent an alternative approach but are laborious and costly to produce, particularly in the early design phases where information and ideas are still vague, as it is illustrated in the video "from physical to digital"

Fig 2.11 | *Screenshot's video "From Physical to Digital"* | 1- interactive sketches: freehand drawing on device visualized inside immersive environment at the same time; 2- from physical to virtual: change immersive environment moving maquette elements on luminous planning table (https://vimeo.com/79087334)

This video (Fig.2.11) presents how linking analogue design tools and digital VR representation has given rise to a new interactive presentation platform that bridges the gap between analogue design methods and digital architectural presentation.
Another example of interactive simulations, is the prototype of augmented reality, *physical model and digital model* (Fig.2.12)

What is relevant: This case in particular, it is very significant on the urban plan simulations through 3D models, and which therefore is closer to the type of solution proposed by the thesis; *It is an example of mixed use of augmented reality, digital models and physical models*. More than the others, tools and techniques adopted by this research group reflect the operation of the Augmented Maquette.

Web: http://cdp.ai.ar.tum.de/videos (visited December 2016)

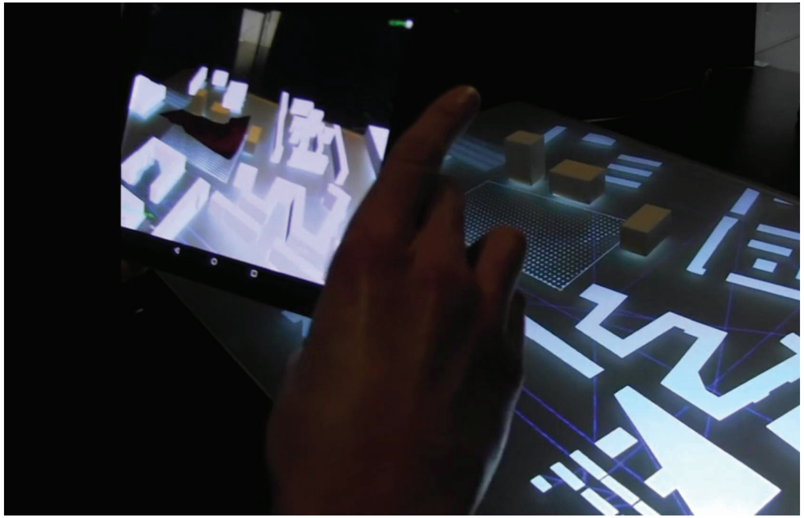


Fig 2.9 | Screenshot's video "Mixed Reality urban design" | (https://vimeo.com/160072114)

03

GEOMETRICAL AND SEMANTIC LEVEL OF DETAILS: COMPARATIVE ANALYSIS OF CITYGML

The chapter address the need to define a clear the framework of level of details relate to 3D models, in order to define a Mockup builder methodology suitable for hosting augmented reality.

The investigation starts with a theoretical framework about the current standards affecting Level of Details of 3D models, and in the second paragraph, perform an analysis of the evolution of these standards so that it is possible to learn everything needed to get a complete picture and go to part two of the thesis, which develops a reference method for the case of applications on physical models: adapt the concept of the level of detail standards for digital models to design a new mockup-specific concept, with the aim of standardizing physical models so they are suitable for use of Augmented Reality as effective simulation tool.

The *Open Geospacial Consortium* (OGC) operates on an international level for the interoperability and the standardization of technologies and geospacial datas; this is the reason why it represents the main reference for level of details standards. In the next section we will analyze OGC standards, defined as *CityGML standards* for universal 3D model, and their evolution, in order to allow the author to carry out the comparative analysis between them.

3 . 1 THE OPEN GEOSPACIAL CONSORTIUM (OGC) CITYGML STANDARDS

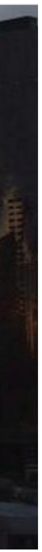
What is OGC?

"The OGC (Open Geospatial Consortium) is an international industry consortium of over 521 companies, government agencies and universities participating in a consensus process and are freely available interface standards. These OGC standards are made through a consensus process and are freely available for anyone to use to improve sharing of the world's geospatial data." (OGC's official website | http://www.opengeospatial.org | visited November 2016)

Vision: A world in which everyone benefits from the use of geospatial information and supporting technologies.

Mission: To advance the development and use of international standards and supporting services that promote geospatial interoperability. To accomplish this mission, OGC serves as the global forum for the collaboration of geospatial data / solution providers and users.

OGC operates in a continuous innovation process, made by the geospacial community to create new standards for exchange and use of geospacial data; proposal for new standards are included inside the OGC Standards Incubator, but these are not official OGC standards, rather they are just “prototypes that push the boundaries of our work and perhaps provide the pathway to future standards” (OGC official website). It is the instrument through which the Consortium collects diversification projects, prototypes and information relating to various proposals of the participants, giving only some guidelines; the commission to review the projects is entrusted to the OGC Technical Committee a couple of times each year.



The OGC’s Innovation Program represents the core of the OGC’s effective process to develop, test and promote their standards. Starting from 1999, the innovation program conducted many initiatives, that provide a fast setting for geospacial technology users and providers to work together in an a agile develop, evolve and demonstrate candidate geospacial standards.

The following are the objectives that such initiatives have proven to:

- **Reduce** technology risk through accelerating development, testing and acceptance of interoperability standards with the refinement of standards and best practices
- **Expand** the market and improve choice by encouraging industry adoption of new standards and best practices, ensuring market availability of interoperable solutions
- **Mobilize** new technologies through providing participants with real world experience and a platform to innovate while driving early adoption of standards
- **Provide** cost effective method for sponsors and participants to share expertise and development while gaining early marketplace insight and advantage

(OGC’s official website | http://www.opengeospatial.org | visited November 2016)

All OGC's IP initiatives, governed by a set of proven policies, process and procedures, are included in these following categories: test beds, pilot projects, OGC engineering services, interoperability experiments, concept development, OGC network. Through these innovation program, initiatives *"build and exercise public private partnership designed to accelerate the development of emerging concepts and drive global trends in interoperability through rapid prototyping of new capabilities"*

How these standards are relevant within the context of this thesis, and on what basis it is developed starting from the OGC standards?

In order to allow and give support to the development of geospacial technology and data interoperability, the OGC Technical Committee provide the OGC Abstract specification. It gives the conceptual foundation for the most OGC Specification development activities. Among these abstracts, there is the CityGML standards specification (0*7-062_OpenGIS_CityGML_Implementation_Specification* | Editors: Gerhard Gröger, Thomas H. Kolbe, Angela Czerwinski, 2007).

*"An increasing number of cities and companies are building virtual 3D city models for different application areas like urban planning, mobile telecommunication, disaster management, tourism, vehicle and pedestrian navigation, facility management and environmental simulations. In recent years, most virtual 3D city models have been defined as purely graphical or geometrical models, neglecting the semantic and topological aspects. [...] **CityGML is a common semantic information model for the representation of 3D urban objects that can be shared over different applications**. The latter capability is especially important with respect to the cost-effective sustainable maintenance of 3D city models, allowing the possibility of selling the same data to customers from different application fields."*

In other words, it is an open dataset model (Geography Markup Language), designed as an open data model and XML-based (Exstensible Markup Language) format for the storage and exchange of virtual 3D city models, in which the same object may be represented in different LOD simultaneously, enabling the analysis and visualisation of the same object with regard to different degrees of resolution.

3 . 2 CITYGML EVOLUTION

CityGML was developed for the first time in 2002 by members of the Special Interest Group, consisting in more than 70 companies, research institutions and municipalities in European country, and than it was sucesfully implemented by a Pilot project by partecipants from Germany; the first CityGML standardized model infact was from Berlin.

CITYGML 1.0: It defines the classes and relations for the most relevant topographic objects in cities and regional models with respect to their geometrical, topological, semantical, and appearance properties. “City” is broadly defined to comprise not just built structures, but also elevation, vegetation, water bodies, “city furniture”, and more.

CityGML standard offers a Level of Detail (LOD) concept that enables the representation of CityGML features from a very detailed to a less detailed description. The core of CityGML features are five definitions about Level of Details for Multiscale digital models:

“**LOD 0** - Regional, Landscape: is essentially a two and a half dimensional Digital Terrain Model, over which an aerial image or a map may be draped.”
“**LOD 1** - City, Region: is the well-known blocks model comprising prismatic buildings with flat roofs.”
“**LOD 2** - City district, Projects: building has differentiated roof structures and thematically differentiated surfaces. Vegetation objects may also be represented.”
“**LOD 3** - Architectural Models (outside), Landmarks: denotes architectural models with detailed wall and roof structures, balconies, bays and projections.”
“**LOD 4** - Architectural Models (interior): completes a LOD3 model by adding interior structures for 3D objects.”

Fig 3.1 | The five levels of detail (LOD) defined by CityGML (source: IGG Uni Bonn)

Tab. 1 | LOD 0-4 of CityGML with its accuracy requirements (source: Albert et al. 2003).

In addition to these definitions, a table is implemented (Tab 3.1) in which are indicated the different standards corresponding to the different Level of Details, and some representative images for each of them (Fig 3.1).

As already said, these standards of CityGML define categories of features from a very detailed to a less detailed description. The less detailed one (*Level of Detail 0*) refers basically to 2.5 dimension models, usefull to show morphological characteristics of the terrain, maps (e.g. land use, etc) and so on. Infact, LoD 0 is associated to a “regional - landscape” definition.

One step further, the new LoD related to “city - region” concept (*Level of Detail 1*) refers to 3D models where first well-known blocks and vegetation appear (e.g. buildings, plants, etc). Hence it was necessary to define some limits regarding block’s dimensions and plant cover, therefore the accuracy (Tab 3.1 - for buildings position/height and generalization) of the entire 3D model; in this case is defined as 5/5m and > 6*6m/3m.

If we increase 3D model’s details, we will reach the first LoD where urban furnitures, solitary vegetation (both prototypes) and roof’s shapes are considered (*Level of Details 2*). It also shows thematically differentiated surfaces, where 3D characteristics are not considered; the blocks accuracy become 2/2m and > 4*4m/2m.

The 4th LoD is the most detailed one related to the street level and associated also to Landmarks (*Level of Detail 3*); almost all details and real form object are included in this kind of 3D model. Surfaces are not only themed, but show also three-dimensional installations.

The highest level of detail which is considered in this classification, is that one for interiors (*Level of Detail 4*); while at the “street scale” details keep their degree, it completes the previous LoD 3 with interiors features.

	LOD0	LOD1	LOD2	LOD3	LOD4
Model scale description	regional, landscape	city, region	city districts, projects	architectural models (outside), landmark	architectural models (interior)
Class of accuracy	lowest	low	middle	high	very high
Absolute 3D point accuracy (position / height)	lower than LOD1	5/5m	2/2m	0.5/0.5m	0.2/0.2m
Generalisation	maximal generalisation (classification of land use)	object blocks as generalised features; > 6*6m/3m	objects as generalised features; > 4*4m/2m	object as real features; > 2*2m/1m	constructive elements and openings are represented
Building installations	-	-	-	representative exterior effects	real object form
Roof form/structure	no	flat	roof type and orientation	real object form	real object form
Roof overhanging parts	-	-	n.a.	n.a.	Yes
CityFurniture	-	important objects	prototypes	real object form	real object form
SolitaryVegetationObject	-	important objects	prototypes, higher 6m	prototypes, higher 2m	prototypes, real object form
PlantCover	-	>50*50m	>5*5m	< LOD2	<LOD2
... to be continued for the other feature themes					

This is the overview about the first concept concerning Level of Details from digital models, but as we will see in the following paragraph, the CityGML 1.0 standards represents only the base of the new LoD concept which was developed later.

CITYGML 2.0: However, this LoD concept of CityGML was no longer *flexible* enough. Several deficiencies of the current LoD concept have been discussed (Benner et al., 2013; Löwner and Gröger 2016; Löwner et al., 2013; Löwner et al., 2015; Biljecki et al., 2013; Biljecki et al., 2014). These are, first, the strict coupling between geometric detail and semantics, second, the preconditions of LoD4 for the interior, and third, only one LoD for interior features.

The LoD concept offers the possibility to generalize CityGML features from very detailed to a less detailed description. This includes a gradual refinement of the geometrical characteristic, but also a more detailed relationship between the geometric and the **semantic properties** (Fig. 3.2); the *Semantic* is the analysis and the study of the language related to the significance. A *CityObject*, (e.g. the *Building*), can in principle be represented multiple times by any geometry type: (Multi-)Solid, (Multi-)Surface, Point, or implicit representation.

J.Benner discussed a new CityGML LoD concept (CityGML 2.0), about the definition of LoD both concerning the Semantic aspect (S LoD) and the Geometrical one , regarding also Interiors or Exterior shell of buildings (Benner et al., 2013).

Inside the table (Tab.3.2) he classified Level of Details, combining these four characteristics; doing this new classification, Benner bypassed the LoD 4, the one regarding interiors of building, because he introduced the Interior aspect.

SLoD-E1	No semantic structuring
SLoD-E2	*AbstractBoundarySurfaces*
SLoD-E3	*AbstractBoundarySurfaces* and *BuildingInstallation*
SLoD-E4	*AbstractBoundarySurfaces* with *AbstractOpenings and BuildingInstallations*

Table 1: Levels of Detail for the semantic structuring of *Building* and *BuildingPart*

GLoD-E0	2D or 2.5 D representation
GLoD-E1	Vertical extrusion solid
GLoD-E2	Generalised real geometry
GLoD-E3	Exact real geometry

Table 2: Levels of Detail for the geometric representation of a building's exterior shell

SLoD-I0	No semantic structuring
SLoD-I1	*AbsractBoundarySurfaces*
SLoD-I2	*AbstractBoundarySurfaces*, *IntBuildingInstallations* and *BuildingFurniture*
SLoD-I3	*AbstractBoundarySurfaces* with *AbstractOpenings, IntBuildingInstallation* and *BuildingFurniture*

Table 3: Levels of Detail for the semantic structuring of *Room*

GLoD-I0	2D or 2.5 D representation
GLoD-I1	Vertical extrusion solid
GLoD-I2	Generalised real geometry
GLoD-I3	Exact real geometry

Table 4: Levels of Detail for the geometric representation of interior building components

Tab. 3.2 | *"Enhanced LoD concepts for virtual 3D city models"* J. Benner et al. ISPRS 8th 3D GeoInfo Conference & WG II/2 Workshop, 27 – 29 November 2013, Istanbul, Turkey | Pag. 56

Fig. 3.2 | Geometric and Semantic features in MRC (Multi Representational Concept) related to CityGML 2.0 | Source and copyright: the author

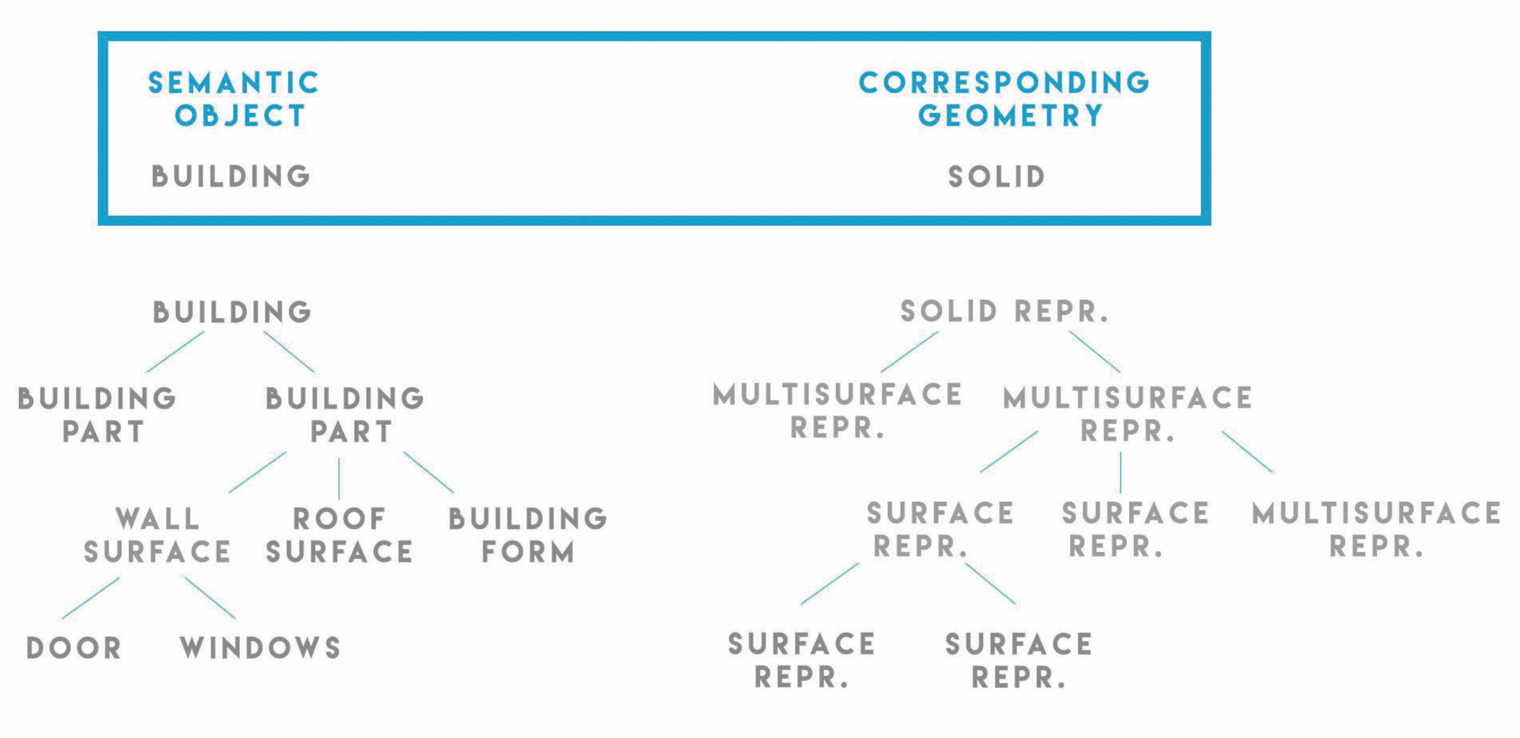


Fig.3.3| Example of different SLoD-E (Source: J. Benner 2013 et al., pag 55) The considered CityObject building displayed as GLoD E3 (Geometrical External level of detail 3) with the four SLoD E (from Semantic level External 0 to Semantic level External 3) | Image copyright: the Author

Thereby he obtained 4 groups of Level of Details: LoD for the semantic structuring of ***building and building parts*** (Semantic LoD - Exterior); LoD for the geometrical representation of building's exterior shell (Geometrical LoD - Exterior); LoD for the semantic structuring of ***Room*** (Semantic LoD - Interior) and the last one, LoD for the geometrical representation of interior components (Geometrical LoD - Interior).

In order to visualize this concept, he provided an example on a LoD 3 model (Fig. 3.3) where each S LoD are displayed. Joachim Benner (2013) proposed also the embedding of old LoDs into the new concept describing the relationship between the new concept and **CityGML 2.0**.

In order to visualize this concept, he provided an example on a LoD 3 model (Fig. 3.3) where each SLoD are displayed. Benner proposed also the embedding of old LoDs into the new concept describing the relationship between the new concept and CityGML 2.0.

Continuing the path trying to develop the not anymore flexible CityGML 2.0, M.-O. Löwner , G. Gröger, J. Benner, F. Biljecki, C. Nagel (2016) proposed a multi-representational concept (MRC) with first, a ***general framework*** and, second, profiles of our concept to support interoperability and backward compatibility, to embed CityGML 2.0 data (G.Gröger, T.H.Kolbe, A.Czerwinski 2007) into the multi representational concept and to reduce complexity.

Actually, one of the main characteristics that define the complexity of CityGML 2.0 LoD concept is: in LoD 0 and LoD1 no further decomposition of *Building* or *BuildingForm* into other feature classes or semantic classification is not possible; on the other hand, the complexity and the accuracy of semantic and geometric increase in LoD2 - LoD4.

They propose *two modifications* to enhance the current LoD concept. First, a strict separation b*etween a geometrical and a semantical LoD and, second, the mapping of the current LoD 4 to four LoD for the interior*. As a result, a building is partitioned into an exterior and an interior, both with one or more explicit LoD of geometrical and semantical aspects.


GLoD E3 - SLoD E0
GLoD E3 - SLoD E1
GLoD E3 - SLoD E2
GLoD E3 - SLoD E3
LEGEND
GLoD: Geometric
SLoD: Semantic
E: External
I: Internal
BUILDING
WALL SUFACE
ROOF SURFACE
BUILDING INSTALLATION
DOOR
WINDOWS

Directly speaking about the CityGML, Nagel et al. (2016) proposed a LoD concept that need 2 important definitions: "*CityObject has a spatial representation in every LoD that refines its spatial representation in higher LoD"* and "*there is no restriction on the usage of any feature type in an LoD.*"

As a consequence of these considerations, feature types that were related strictly to the LoD4 CityGML 2.0 now can also be represented in lower LoDs (explained in the follow paragraph). For the other LoD, the general characteristics remain the same: LoD 0 stands for planar representations, LoD 1 for prismatic blocks model, LoD 2 represents generalised shapes of CityObjects, whereas LoD 3 represents the highest geometrical complexity.

The core of the new multi-representational concept are Profiles (M.-O. Löwner , G. Gröger, J. Benner, F. Biljecki, C. Nagel 2016) supporting the backward compatibility and interoperability between CityGML 2.0 and the new flexible concept.

The structure of a profile is quite simple: it assigns a geometry type (Multi-)Solid, (Multi-)Surface, (Multi-)Curve, Point, or implicit representation and a geometric definition to each feature type. Profile is identified by a *ContextIdentifier* that consists in of the level (in a specific namespace) together with **module name** and the **feature type** name.

For example, the *Profile* for *Building* in module building in LOD2, has the ContextIdentifiers *CityGML2.0/LoD2/Building/Building*; and again, the Profile for Building in module *Openings* in LoD 4 has the ContextIdentifiers: *CityGML2.0/LoD4/Building/Opening* with their corresponding geometry type Multi Surface Repr. and Implicit Geometry Representation (Tab.3.3).

	CityGML/2.0/ LoD0	**CityGML/2.0/ LoD1**	**CityGML/2.0/ LoD2**	**CityGML/2.0/ LoD3**	**CityGML/2.0/ LoD4**
Building/ Building	Multi Surface Repr. horizontal surfaces, footprint/roof edge	*Multi Surface Repr.* *Solid Repr.* prismatic blocks model with vertical or horizontal boundary,	Multi Curve Repr. Multi Surface Repr. Solid Repr.		
Building/ WallSurface	/	/	Multi Surface Repr.		
Building/ CeilingSurface	/	/	/	/	Multi Surface Repr.
Building/Room	/	/	/	/	*Multi Surface Repr.* *Solid Repr.*
Building/Building Installation	/	/	*Geometry Repr.* *Implicit Geometry Repr.*		
Building/Opening	/	/	/	*Multi Surface Repr.* *Implicit Geometry Repr.*	

Tab. 3.3 | Table describing profiles for backward compatibility (M.-O. Löwner et al. 2016, pag. 7) | Geometry types in italics; contextIdentifiers are derived from the current LOD names (in the name space CityGML 2.0) combined with the modules/feature type in the first column.

This kind of CityGML standards concept looks much more complex than the previous version, but become also much more flexible, because CityGML 2.0 gives not only an indication about characteristics of models (measurements, dimensions, typology of objects, ect) in a generic framework, but each elements has its own classification (ContextIdentifiers) given by different features as a *geometry types*.

CITYGML 3.0: What happens at this point is a very different outcome compared to the previous configuration (CityGML 1.0); in this last version of there is the loss of the characteristics associated with the object's accuracy inside the 3D model. It became necessary to create another solution in order to overcome this problem (Löwner 2016).

The result of this combination between CityGML 1.0 and CityGML 2.0 is proposed as the arrival and a new solution for a new CityGML (3.0) more flexible and customizable (Tab.3.4); LoD4 is not visible because as was already described, is not considered anymore as a separated level of details. It is to keep in mind that this new proposal should not be considered as "final", but a study on how to make more accessible the virtual 3D models.

The structure of the matrix is the same of CityGML 2.0 profiles, composed by the level of detail, and the module/future type in the first column; what is implemented regards all 3D model characteristics description related to the first LoD classifications (Albert et al. 2003) and the Geometrical type related to the last LoD concept (M.-O. Löwner 2016).

In order to explain in a more clear way the composition of CityGML 3.0 (tab.4) the author will give an example by explaining step by step one of the modules / feature types for each level of detail proposed, from LoD 0 to LoD 3 of *Building/BuildingPart*:

As already specified, inside the first row on the top the LoD name is indicated, while in the first column there is the Module/future type that we are going to analyze, in this case, the BuildingPart.

Under LoD 0, the lowest detailed, first of all specifies the geometry type: Multi Surface, Surface and Point Representations, because as described in the description, we are talking about 2D or 2.5D representations, which may include indications on multiple surfaces (contours of building blocks, vegetation coverings, land use indications, ect) or interesting landmarks which are point representations.
Continuing with the analysis, LoD 1 of 3.0 version merge the geometrical feature, mainly *Solid representation since prismatic blocks* are the predominant part of this category of models.

Both LoD 2 and LoD 3 have the same geometry type, because they starts to include features as overhangs, building details, benches; The first one is a bit more generalized (roof shape, standard type for vertical boundaries, ect); the second one, reproduce exactly the real environment at the street level.
Level of Detail related to interiors (known as LoD 4) is not mentioned because for interiors there are separate levels that are detached from the exterior shell.

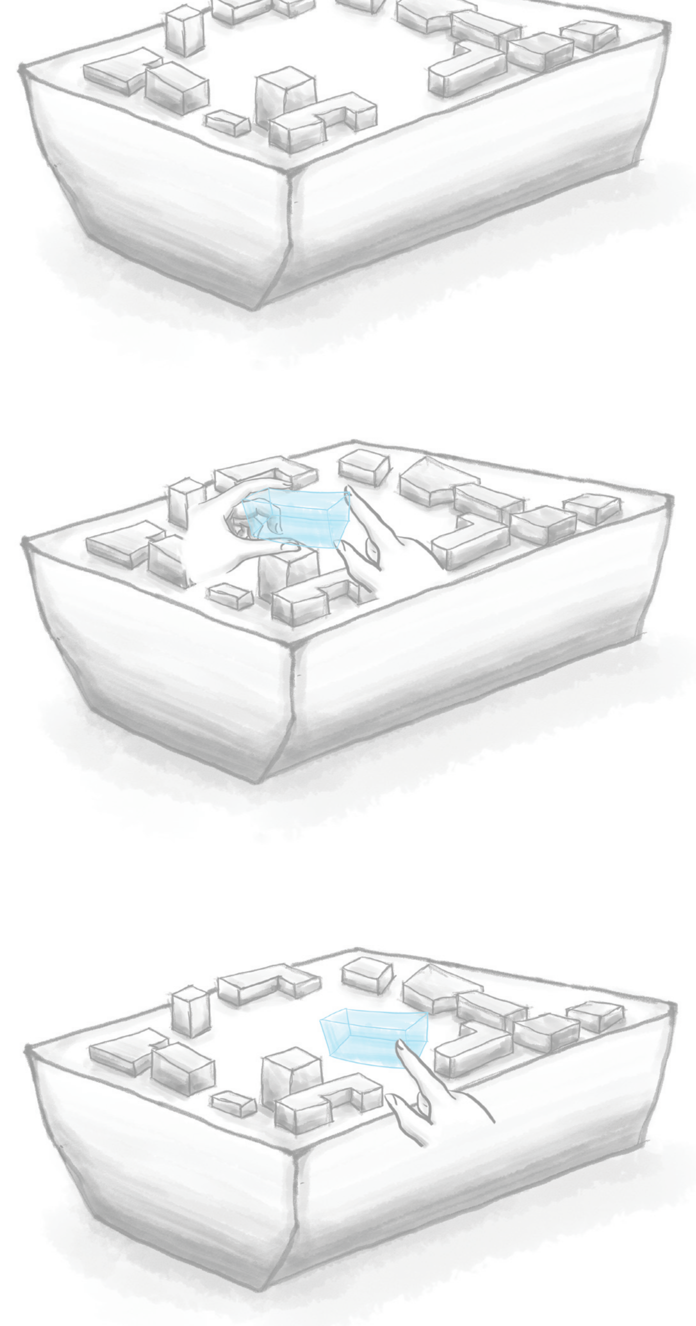
Tab.3.4 CityGML 3.0 new proposal building module| (M.-O. Löwner 2016, pag. 8) Geometry types in italics; contextIdentifiers are derived from the current LOD names (in the name space CityGML2.0) combined with the modules/ feature type in the first column.

	CityGML/3.0/LoD0	CityGML/3.0/LoD1	CityGML/3.0/LoD2	CityGML/3.0/LoD3
Building/ Building **Building/ BuildingPart**	*Multi Surface Repr.* *Surface Repr.* *Point Repr.* non-vertical (2.5D) surface, measured at footprint level, roof edge level or any level	Solid Repr. prismatic blocks model with vertical or horizontal boundary, unique height	*Solid Repr.* *Multi Surface Repr.* prismatic blocks model (with vertical boundary) with standard type, generalized roof shape, roof overhangs (opt), dormers/chimneys (opt) if shell is represented as solid, multi surfaces are restricted to roof overhangs	*Solid Repr.* *Multi Surface Repr.* *Multi Curve Repr.* architectural models
Building/ WallSurface	*Multi Curve Repr.* *Curve Repr.* projection of wall surface onto footprint (of building or storey)	Surface Repr. Vertical	*Multi Surface Repr.* *Surface Repr.*	*Multi Surface Repr.* *Surface Repr.* architectural models
Building/ RoofSurface	*Multi Curve Repr.* *Curve Repr.* 1D boundary of horizontal LoD1 roof surface	Surface Repr. Horizontal	*Multi Surface Repr.* *Surface Repr.*	*Multi Surface Repr.* *Surface Repr.* architectural models
Building/ Ground Surface	*Multi Curve Repr.* *Curve Repr.* 1D boundary of horizontal LoD1 ground surface	Surface Repr. Horizontal	*Multi Surface Repr.* *Surface Repr.*	*Multi Surface Repr.* *Surface Repr.* architectural models
Building/ Opening	*Multi Curve Repr.* *Curve Repr.* *Point Repr.* projection of opening onto footprint (of building or storey) if represented as curve	Surface Repr. rectangle (vertical), cuts no hole / cut out in BoundarySurfaces or solid boundary	Surface Repr. Rectangle	*Multi Surface Repr.* *Surface Repr.* architectural models
Building/ Room	*Surface Repr.* *Point Repr.* footprint of room (floor level, ceiling level, …)	*Solid Repr.* prismatic blocks model with vertical or horizontal boundary, unique height	*Solid Repr.* *Multi Surface Repr.* prismatic block with standardized, generalized ceiling shape and dormers (opt)	*Solid Repr.* *Multi Surface Repr.* architectural models

3 . 3 TOWARDS THE AUGMENTED MAQUETTE

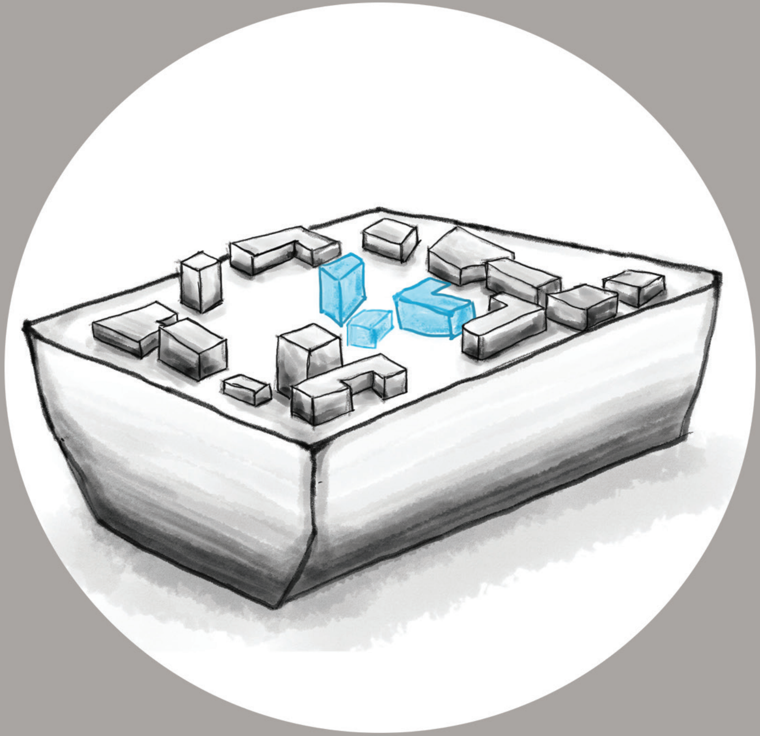
The theoretical framework and the significant case studies are the basis for the following part, which develops a reference method for the case of applications on physical models: definition of a new matrix that will encompass everything regarding the new CityGML LoD, both Geometrical and semantic features of digital 3D models.

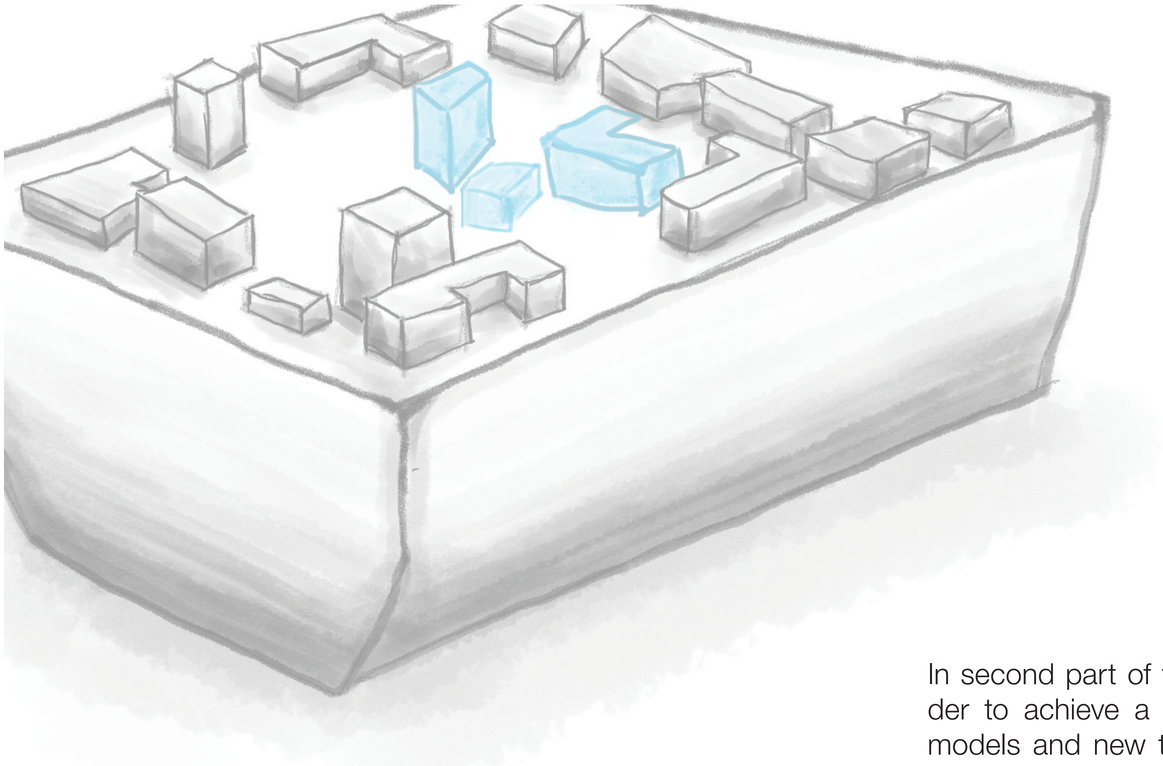
Hence, the Second part of the Thesis Adapt the concept of the *level of detail standards for digital models to design a new mockup-specific concept*, with the aim of standardizing physical models so they are suitable for use of Augmented Reality as effective simulation tool.



PART TWO

AUGMENTED MAQUETTE





In second part of the thesis the author's path will begin in order to achieve a good final mixed solution between scaled models and new technologies: the *Augmented Maquette*. In fourth chapter, after having thoroughly studied the comparative analysis of the level of detail standards along with reflections on the different scales of representation, has made it possible to merge all information in one unique solution; afterwards, the fundamental transition between digital and physical, that is described in chapter 5, definition of the *level of details for physical models*. These M LoD in turn define a pattern classification, devoted to certain types of simulation; Thus represent a powerful tool for project simulations, as in this case through Augmented Reality. They are therefore different from other types of mock-up only designed to have a *conceptual physical restitution*, those known as conceptual models.

04

PROPOSAL OF LOD CONCEPT FOR PHYSICAL MAQUETTE

As already anticipated at the end of the first part of the text, the beginning of the practical journey towards the Augmented Maquette is the realization of a matrix that will put all the information and notions about level of details standards into a unique system. Panel 1 "*New CityGML LoD concept*" takes in consideration all the standard's storyline previously analysed; It includes not only *semantic* and *geometrical* definitions and relationship, but also a *visual representation*

As we can see it has 4 main components: (i) the relationship between semantic object and its corresponding geometry; (ii) a representation of the CityObject with the highest geometrical level of detail (Fig 4.1); (iii) the Matrix.

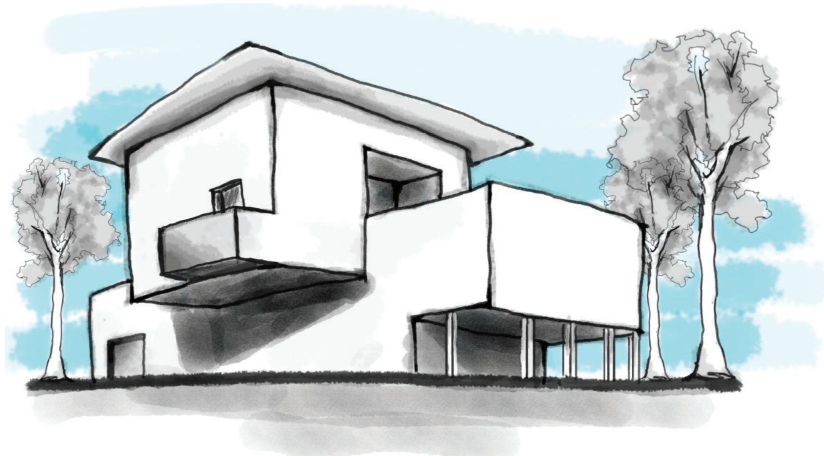
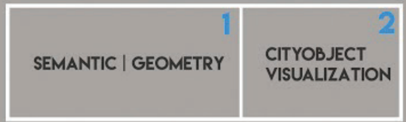


Fig. 4.1 The CityObject/Building - Geometrical representation of G LoD E3

PANEL 1 NEW CITYGML LOD CONCEPT

GEOMETRICAL AND SEMANTIC RELATIONSHIP



EMBEDDING OF OLD LODS IN THE NEW CONCEPT

G LOD E0 Geometrical Level of Detail External 0 |
2D or 2.5D representation

G LOD E1 Geometrical Level of Detail External 1 |
Vertical extrusion solid

G LOD E2 Geometrical Level of Detail External 2 |
Generalized real geometry

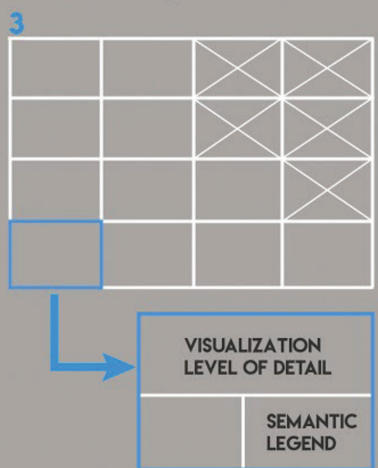
G LOD E3 Geometrical Level of Detail External 3 |
Exact real geometry

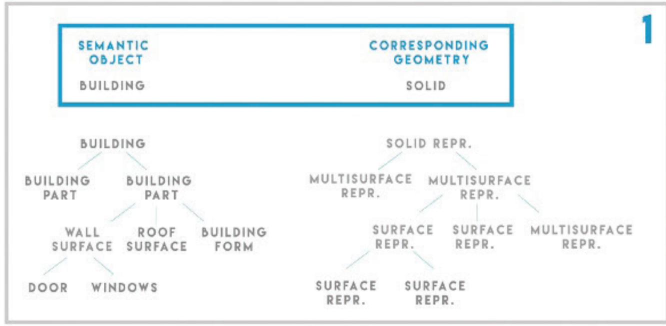
S LOD E0 Semantic Level of Detail External 0 |
No semantic structuring

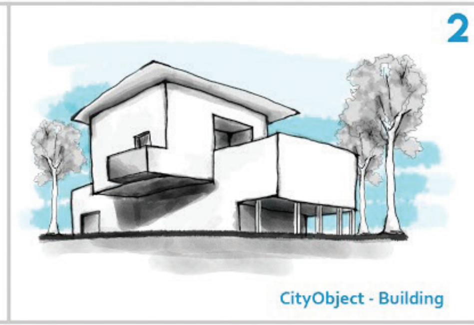
S LOD E1 Semantic Level of Detail External 1 |
AbstractBoundarySurfaces

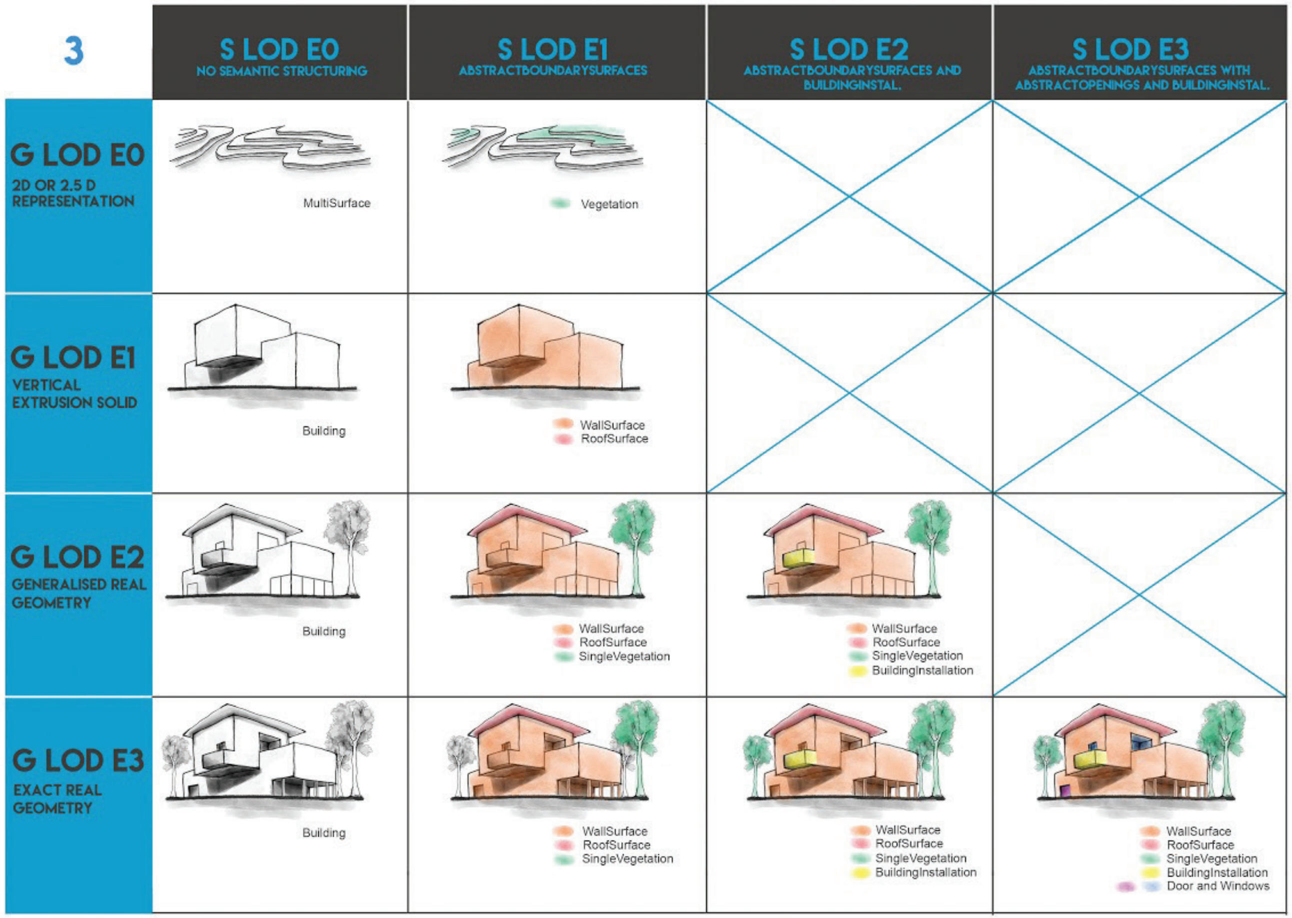
S LOD E2 Semantic Level of Detail External 2 |
AbstractBoundarySurfaces and BuildingInstal.

S LOD E3 Semantic Level of Detail External 3 |
AbstractBoundarySurfaces with AbstractOpenings and BuildingInstal.









Panel 1 | New CityGML LoD concept | Shows the result of crossing information and achieved studies regarding Level of Details for Digital 3D Models, related both to Semantic and Geometrical aspects. This represents the base to draft Maquette Standards. RIGHT: Legend; TOP: 1- scheme of Geometrical/Semantic. 2- CityObject Building; BELOW: Matrix of SLoD and GLoD | Image Copyright: The Author

4 . 1 SYSTEMATIZATION: CITYGML 3.0 THE NEW LOD CONCEPT

· Scheme regarding the re-elaborated relationship between *semantic object* and its *corresponding geometry* expressed by J.Benner (2013), in order to show how a geometrical representation of a virtual 3D model is considered as a semantic object (e.g. semantic object *Building part* corresponds to the geometry *Multisurface representation*) in a more clear and linear way.

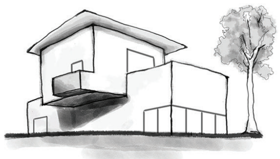
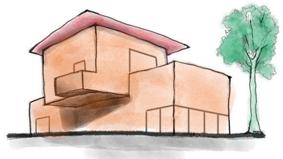
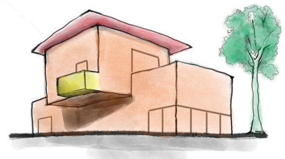
· In order to introduce a graphical representation about the 3D model, section 2 of the panel shows the object of this study used as example, the *CityObject* (Building) with the highest geometrical level of detail (corresponding to G LoD E3). This image will help to visualize both semantic and geometrical concepts inside the Matrix;

· This third part that we called *Matrix* represents the core, the combination between Geometrical LoD concept, the Semantic LoD concept, how they are embedded in the new level of details concept and their visual outcome.

The first important aspect related to this table regards only the External part of models (LoD 4 is now considered as a specific category of LoD defined Interior); *Embedding of old LoDs in the new concept* (J.Benner, 2013) shows the classification of new LoDs (e.g. G LoD E2 corresponds to the *External Geometrical Level of detail 2*, and S LoD E2 corresponds to External Semantic Level of detail 2, and so on) which are located in the blue column and the black straight.

There’s also an additional information to the name, key concepts both for semantic and geometrical ones, in order to catch

To have a clear picture of the matrix's operation, the author will analyze a row in detail:

	S LOD E0 NO SEMANTIC STRUCTURING	S LOD E1 ABSTRACTBOUNDARYSURFACES	S LOD E2 ABSTRACTBOUNDARYSURFACES AND BUILDINGINSTAL.	S LOD E3 ABSTRACTBOUNDARYSURFACES WITH ABSTRACTOPENINGS AND BUILDINGINSTAL.
G LOD E2 GENERALISED REAL GEOMETRY	 Building	 WallSurface RoofSurface SingleVegetation	 WallSurface RoofSurface SingleVegetation BuildingInstallation	

The abstract (Fig. 4.2) shows the interoperability between the geometric level defined as LoD 2 and its semantic characteristics (S LoD Ex). In the first column there is the definition of Geometrical LoD (External 2) which is defined by standard fees up to the first version, CityGML 1.0, followed by a brief indication of the appearance of the model and what it contains, in this case "generalized real geometry". The black row instead, explain different Semantic Level of Details contained in G LoD E2 itself, from S LoD E0 to S LoD E3; as it was in the blue column, the name is followed by a description, but from the features that semantically decomposing the exterior shell :

[...] *"These features are either BuildingInstallations or AbstractBoundarySurfaces (WallSurface, RoofSurface, GroundSurface, OuterFloorSurface, OuterCeilingSurface or ClosureSurface), which in the highest SLoD-E refer to AbstractOpenings (Doors and Windows)."* [...] (J. Benner et al. 2013)

Therefore, starting from S LoD E0, where we only have one semantic feature (Building), G LoD E2 can reach a maximum Semantic accuracy with the 3rd level; the last box of course is empty due to the absence of ***AbstractOpenings***, which are given by an higher G LoD.

What is missing inside the Matrix showed on Panel 1, are information about the old concept of LoD 4. As it is already said above, Benner (2013) bypassed the LoD 4, the one regarding interiors of building, because he introduced the ***Interior*** aspect. Had only one single Level of Detail for interiors was less flexible and full of constraints, especially regarding the semantic aspect; it's what complete G LoD 3. In this new concept, LoD 4 can also be represented in lower LoDs.

	SLoD-E0	SLoD-E1	SLoD-E2	SLoD-E3
GLoD-E0	0			
GLoD-E1	1			
GLoD-E2	2	2	2	
GLoD-E3	3	3	3	3

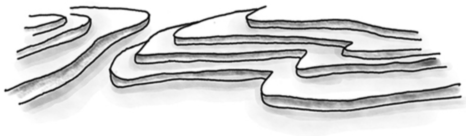
	SLoD-I0	SLoD-I1	SLoD-I2	SLoD-I3
GLoD-I0				
GLoD-I1				
GLoD-I2				
GLoD-I3	4	4	4	4

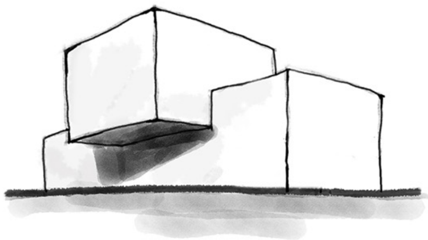
LOD0	LOD1	LOD2	LOD3	LOD4

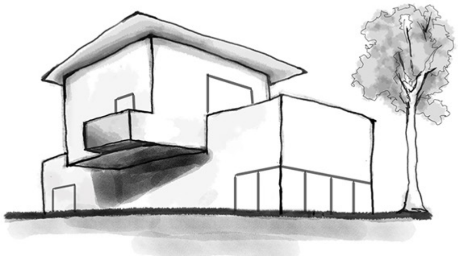
Tab. 4.1 Embedding of old LoDs in the new concept (Source: J. Benner et al. 2013) | RIGHT: External LoDs; LEFT: Internal LoDs

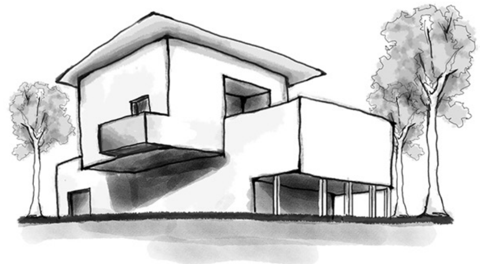
The Table (Tab. 4.1) shows the embedding of old LoDs in the new concept, where LoD 4 is configured separately. Infact, the table on the right, is the same matrix displayed inside Panel 1 (regarding External Level of Details), whereas LoD4 is related to the LoD - I (Level of Detail - Internal).

In this thesis, the aspect regarding Internal LoD will not be studied in deep because the aim is to face a comparative analysis to *establish the level of details of the physical model to the urban scale level.*









4 . 2 DEFINING "LEVEL OF DETAILS MAQUETTE"

In the previous section we have discussed the evolution of the concept of levels of detail on the 3D models, but it was only about digital models, which therefore possess certain characteristics, and are deficient in other aspects. Hence the final goal is to *codify relationships between physical models and digital models in terms of level of details in order to optimize a combined use* (AR) it is crucial to find a sensible and coherent adaptation with previous definitions on digital detail levels for a new proposal of a Physical LoDs matrix.

The main difference between the two models (digital and physical), which is also the main feature that defines a physical model, is in the *scale* of representation. What defines the level of detail of the maquette is precisely the scale with which you decide to build the model itself; to attribute such characteristics of the physical model are achievable with the right quality at the end of a good yield and with the right scale to the appropriate Level of Detail.

For convenience, we will refer to the **maquette standards** with M LoD (Maquette Level of Details). A key thing to keep in mind during the whole analysis, is that the final intent of both the identification of the mockup standards, *making them excellent support tools for the simulations and evaluations of the project*, in such a way that the result is appropriate and as faithful as possible. This does not mean that we have to produce a perfect copy of reality in one to one scale, but a certain degree of realism in its anticipation is essential (Bosselmann, 1998).

During this phase, one step back is needed; it is therefore necessary to associate with each LoD the right scale, relying not only on the *analysis of the elements and attributes that will be made in the preliminary model, but also on previous definitions of scales and themes of focus*. In general, the less detailed classification of scales, illustrated in *"Symbiosis in Design"* by the japanese architect Kisho Kurokawa (1991), is considered:

LEVEL	DESIGN SCALE	THEME	
Context	1:1000 / 1:500	Place	situation, programme, environment, orientation
Form	1:200 / 1:100	object	geometry,shape, plasticity, border, combination
Structure	< >	organization	system, measure, framework,wall, contruction
Surface	1:50 / 1:20	arrangements	façade,pattern, rhythm,balance, arrangement
Technique	< >	articulation	material, product, dimention, profile, bond
Detail	1:10 / 1:5	feature	component, connection,joint, colour, ornament
Information	1:1 /legend	symbol	

Tab. 5.1 | Jack Breen (2013) EAEA-11 Conference 2013 Envisioning Architecture: Design, Evaluation, Communication "Designing Visualisation: Conception, Methods, Models, Perceptions" Pag. 14

- Large, urban (and regional) planning and design;
- Medium, building design (commonly identified as Architecture);
- Smaller, Interior design and detailing.

Subsequently, Jack Breen (2013) proposes a very precise framework that suggests a general view on the relative scales of the different project levels, and the corresponding information on the various areas (Table 5.1). The framework is then made up of different levels, each with a different **theme name**, an appropriate ***scale* range** and a list of **design issues** that synthesize.

Inside the first column ***Level*** , which is a kind of ID name, indicate different categories related to the ***Design Scale*** column, defined different ranges of scale; for each level, is assigned a ***Theme***, and general list of features included.

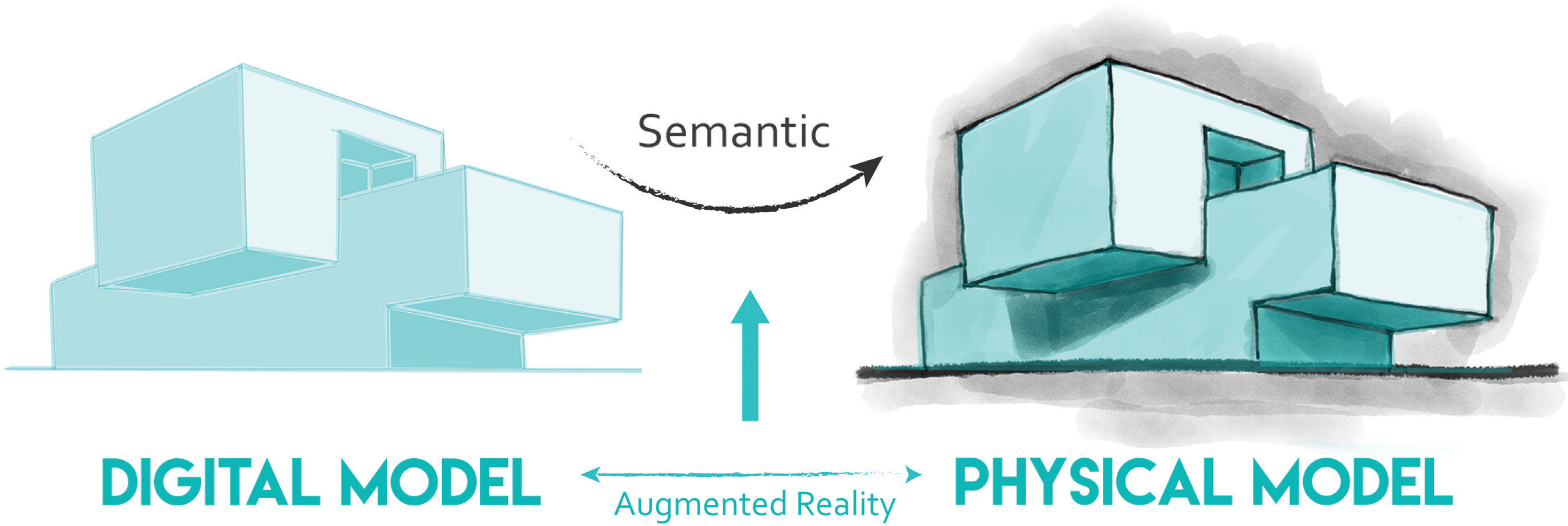
This framework gives the first basis together with LoD structure to the drafting of M LoD (maquette). Obviously, categories of levels are more than the classification of LoDs (five); an important step will be ***comparing these data***, to derive a single ***framework***.

There is no single definition for LoD, many people contribute to the work by giving their interpretation; it is wrong to exclude and even eliminate some previously defined concepts.
For the definition of M LoD it is necessary to take into consideration all that has been said before on account of level of details, to extract the most important information which describe the characteristics that will define various levels.

What is relevant?

As it regards the semantic aspect, the question changes. Staying in the digital environment, characteristics which set a model in a given S LoD, were implicit; represent them visually is complex without the digital support. Hence augmented reality (Fig. 5.1) will play a key role in the inclusion of semantics in maquette. The semantics of the elements then could be implemented on the maquette by AR; in the next chapter it will be explained how ***augmented elements*** will be implemented.

Fig. 5.1 *Integration of Semantic in Physical Maquette* | Semantic characteristics could be implemented on a physical maquette though augmented elements, overcoming constraints linked to the problem of hidden informations contained in a digital model | Image copyright: the Author



The first step as regards the identification of M LoD , which is also what distinguishes a maquette from a digital model, is the scale of the detail (Breen, 2013).

The second is to reconsider the preliminary classification of Level of Details, from LoD 0 to LoD 4. In this field, LoD 4 is considered as level of detail equal to others, for a simple logical and practical reason: we are talking about **physical scaled objects**, this implies that in some scales, you can not represent the interior of the buildings, because physically too small (depth in the next section).

All that was related to their general characteristics and definitions of standards in terms of accuracy is one thing to keep surely, slightly adapted in some cases as a matter of implementation / performance of the physical model. The concept expressed on G LoD is to maintain as a general indication.

First you have to define the equivalent of G LoD, explain and justify them, and then introduce the digital part, explaining the tools and how to use them depending on the M LoD.

The key element, which leads to define specific M LoD and creating differentiations between them and digital LoD as we already said, is the **scale** of representation, just because for the physical model, to determine the level of detail is precisely the scale with which the maquette is made, without the possibility of increase or decrease (such as Zoom In/Out). What does it mean on a practical level?

Elements represented within a model are characterized by a real dimension, which is then transported within a model; the difference between the physical and digital is precisely at this stage, where the digital model is drawn directly into the actual size and then, through the zoom tool , it can be scaled; in the physical model you need to decide at the beginning of its realization the scale of representation. Therefore, it becomes essential to be aware of what you want to represent in the maquette, so as to choose the appropriate M LOD, and thus the scale of representation. This is because some objects must have a certain size to be able to be represented with a good yield.

The scales derived by Jack Breen studies (2013), which indicate the Level of Details of the maquette, represent the minimum scale value that the model must have to be framed in ***that level of detail*** (an object included in M LoD 0 will be represented up to grade 4 of level of details, but not viceversa).

As practical example, if we have a 1:10 mockup, it can be realized from the highest level of detail (LoD 4) to the lowest (e.g. only volumes); but a 1:10000 mockup, can't be realized with details because the result it will not be enough acceptable for a simulation. The basis on which to identify the various scale ranges of M LoD is in the ***feasibility level of the object***. To clarify this concept, just take as an example a simple object such as a chair, and reason on its representation in different scales (Fig. 5.2)

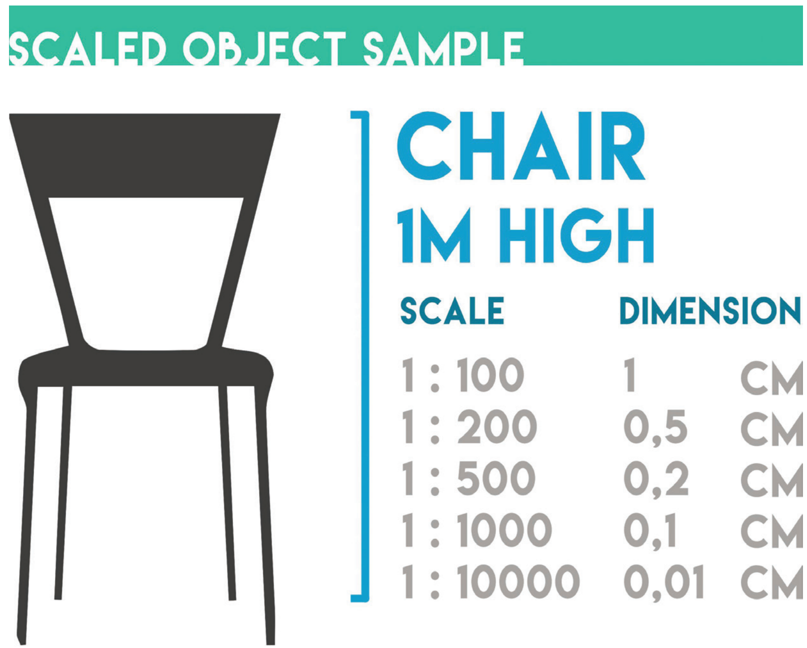


Fig.5.2 Scaled object sample |
Source and copyright: the author

The choice of lead as an example a furniture lies in the fact that this type of object is included in the Level of Details 4, the more detailed and therefore often includes the realization the interior of the buildings.

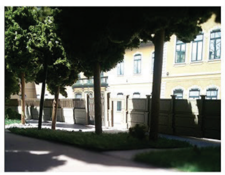
In the example image (Fig. 5.2) shows effective measures that a chair of one meter height would have within the various maquettes, identified with five allocated stairs. It found that the ultimate purpose is the optimal realization of the maquette so that the simulations are exhaustive, a chair made in an upper scale to 1: 100 would be too small size to be able to physically realize; to respond to an hypothetical objection to the possible implementation of the subject in 1: 200 scale, is to consider this: an object such as a chair, a height of 0.5 cm scale, is so physically feasible, but its display within a simulation would fail to reach a level of detail as to be realistic.

With this background, you can finally draw a real classification of level of details maquette (next page, Panel 2).

The table shows the result of the *Comparative Analysis* and the final outcome regarding Level of Details for physical models; this matrix incorporates definitions of scales by Jack Breen (with their denominations) adapted to the physical models according to the *criteria of feasibility*, together with the *CityGML standards* model, since its first draft up to the latest versions (2.0 and 3.0); below, shows the descriptions of each *model / feature type* (black row). More specifically, inside blue column there is the identification of each M LoD, given by a *name*, a *theme* (focus), a description about *general characteristics* of the maquette and a *range of scale*.

PANEL 2 LEVEL OF DETAILS MAQUETTE

Analysis of level of details in physical models Starting from CityGML Standards: definition of LoD M (level of details maquette), identified by a name, a theme, a description about general characteristics of the maquette for each Level of Details and a range of scales (blue column); Definition of Model/Feature type name (black row) for each LoD M, through the geometrical representation and a description (rows)

	Image	Building / BuildingPart	WallSurface / RoofSurface	Openings	City furniture	Vegetation / Plant Cover
LOD0 M CONTEXT 1 : 10000 / 1:1000 **PLACE** situation, environment orientation		Multi Surface Repr. Surface Repr. Point Repr. Non-vertical (2.5D) surface, measured at footprint level, roof edge level or any level Height/Footprint accuracy: maximal generalization.	Multi Curve Repr. Curve Repr. Horizontal Boundary			Surface Repr. Plant cover > 5ºx5º (m^2)
LOD1 M FORM 1 : 1000 / 1 : 500 **OBJECT** geometry, shape, border plasticity, combination		Multi Surface Repr. Surface Repr. Point Repr. Prismatic blocks model with vertical or horizontal boundary. Height/Footprint accuracy: > objects 6x6 / 3 (m^2 / m)	Surface Repr. Horizontal roof, vertical surfaces or unique height (maquette flat)			Solid Repr. Surface Repr. Solitary vegetation > 12 m Plant cover > 5ºx5º (m^2)
LOD2 M STRUCTURE 1 : 500 / 1 : 200 **ORGANIZATION** framework, system, wall construction		Solid Repr. Multi Surface Repr. Prismatic blocks model with thematically differentiated surfaces, optional roof overhangs. Height/Footprint accuracy: > objects 4x4 / 2 (m^2 / m)	Multi Surface Repr. Surface Repr. Generalized roof type and orientation; thematized vertical boundary (with images or lasercut)	Surface Repr. Printed openings	Multi Surface Repr. Multi Curve Repr. Point Repr. Prototypes, Vehicles, people, fences, banches. Detailde ground surface.	Solid Repr. Solitary Vegetation > 6 m
LOD3 M SURFACE 1 : 200 / 1 : 50 **ARRANGMENTS** facade, pattern, rhythm		Solid Repr. Multi Surface Repr. Multi Curve Repr. Denotes architectural models with balconies, overhangs, bays ect... Choise of specific materials for objects. Height/Footprint accuracy: > objects 2x2 / 1 (m^2 / m)	Multi Surface Repr. Surface Repr. Detailed walls and roof structures with real object form.	Multi Surface Repr. Real object form	Multi Surface Repr. Multi Curve Repr. Solid Repr. Real object form; vehicles, people, fences, banches. Use of specific material for each element Detailde ground surface.	Solid Repr. Solitary vegetation > 2 m
LOD4 M DETAIL <1 : 50 **FEATURE** material product, dimension, profile, band		Solid Repr. Multi Surface Repr. Multi Curve Repr. Completes a LoD 3 model adding interior structures for 3D objects	Multi Surface Repr. Surface Repr. External shell could be from LoD 1 M to LoD 3 M	Multi Surface Repr. Real object form	Multi Surface Repr. Multi Curve Repr. Solid Repr. Real object form, interior details	Solid Repr. < Lod 2 M

Panel 2: Level of Details Maquette | Starting from CityGML Standards: definition of LoD M (level of details maquette), identified by a name, a theme, a description about general characteristics of the maquette for each Level of Details and a range of scales (blue column); Definition of Model/Feature type name (black row) for each LoD M, through the geometrical representation(in blue) and a description | image copyright: the Author

Before proceeding to the next paragraph, where all M LoD will be illustrated, an explanation about each **model / feature types** (black row) is needed.

IMAGE: The images allow to have a visual match with the physical model relating to the level of detail that characterizes it. The images in question are closely linked to the description that accompanied inside the table; their definition derives from the analysis made on digital LoD provided by CityGML standards. The logic that has led to the development of the preliminary model standards, in particular as regards the physical characteristics of the model, is that of decoding the data relating to the digital Level of Details, extracting them from the preset tables in the form of measures and definitions in order to recreate a one sample of the physical model that encompasses all the features.

BUILDING / BUILDING PART: Mainly describe the type of "form" that defines the pattern, especially as regards the buildings; moreover provide a small picture on the types of details / objects, which are then further described in the following columns. In this section is also indicated the minimum height and base area of CityObjects that will be represented. With the increase in the level of detail, you can then represent the maquette smaller and smaller objects (height accuracy and the footprint).

WALL SURFACE / ROOF SURFACE: This column indicates the level of accuracy of the facades and roofs; with the increase of the LoD M, they will always be more detailed, from simple flat and uniform texture, to enrichment of details such as the overhangs, or use of different materials for the construction of different elements that make up both roofs and facades.

OPENINGS: It is relevant to understand from which LoD m openings appears and also how they are represented in a physical model.

CITY FURNITURE: Not simple definitions as a single word (object, prototype, ect ...) but a sort of list of items/objects belonging to street furniture and all that contributes to the enrichment of elements the physical model. This derives from the analysis of the intervals set on the size of the objects to be displayed on the maquette.

SOLITARY VEGETATION / PLANT COVER: The first concerns the individual natural elements, the second is related to the extension surface of green masses in the area. In the first case, the minimum effective heights that plants (generally trees) are pointed must have in order to be realized are inserted inside the maquette; the same applies for the second case, with the difference that the dimension to be considered is no longer the height, but the surface area, and therefore the coverage area in sqm.

As already mentioned, the scaled model is usually considered a good support tool in architectural and urban design, and scale plays a key role in a topical focus and the related abstraction and level of detail; being a physical model commonly used as a conceptual tool, there is what is called “level of abstraction” of architectural model (M. Stellingwerff et al., 2013) tightly bound to the scale. This topic will not go deeper in this text as it deals with different types of models than the ones concerned.

4 . 3 MAQUETTE STANDARDS

Keeping in mind the main concept of M LoD, that they represent the minimum scale value that the model must have to be framed in the level of detail (an object included in M LoD 0 will be represented up to grade 4 of level of details, but not viceversa), we give a framework in order to have a classifications of maquette standards, which will give support in the understanding of which type of plastic is *most suitable for a simulation*.

M LOD 0 CONTEXT

The models with this kind of detail are mainly used for playing generally very large areas of land, where you must also include the **context** and the morphology of the terrain (2.5D). For this the starting scale which defines the LoD 0 M it is of 1: 10000/1: 1000.

Basically, the contour lines and natural elements are the main elements that characterize this level of detail; it is possible the insertion of architectural elements, but only in the case of mock-flat (i.e. those models in which is not indicated the heights of buildings and / or blocks of buildings), or in the case of very large buildings (in reference to the context) or landmarks.

This concept is more detailed in defining the heights and superficial extension of elements to represent.

Image	Building / BuildingPart	WallSurface / RoofSurface	Openings	City furniture	Vegetation / Plant Cover
	Multi Surface Repr. Surface Repr. Point Repr. Non-vertical (2.5D) surface, measured at footprint level, roof edge level or any level Height/Footprint accuracy: maximal generalization.	Multi Curve Repr. Curve Repr. Horizontal Boundary			Surface Repr. Plant cover > 5ºx5º (m^2)

For the extensive areas, which are generally represented in these preliminary model, the main type of element defined as maximal generalization (only elements defined by a surface extension), and may be for example the use of the soil. The same may hold true for the volumes, that except for very large buildings, will be represented not in scale reporting the heights.

Consequently, should not be considered forms of roofing, street furniture and greenery isolated on their too small size if shown in this scale. Unlike the single vegetation, it is instead possible to the representation of green masses with a relevant extension, with a minimum area of 50 x 50 sqm.

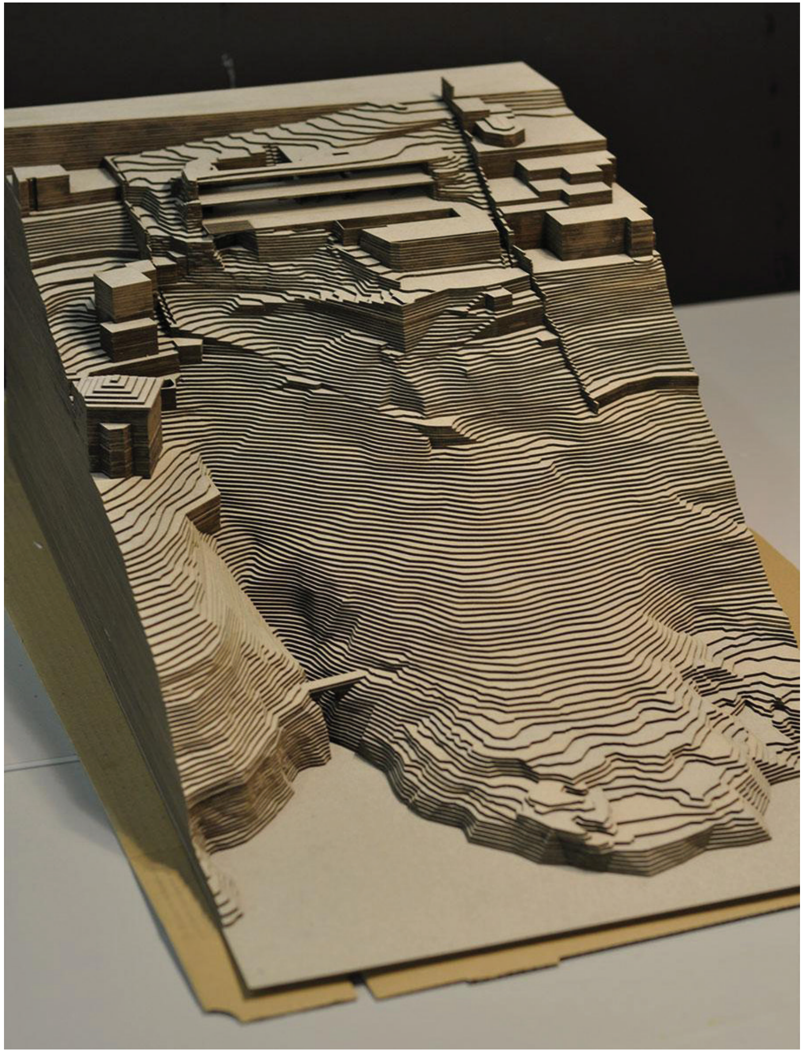


Fig.5.3 “maquette en carton” | Atelier figura/sfondo Jean Nouvel

M LOD 1 FORM

Reaching this kind of detail, a physical model begins to reach the first real step closely related to the visualization of an urban environment, starting from a scale value of 1: 1000 up to 1: 500. Using this dimensioning, it is possible to create a preliminary model in which the morphology is visible so far.

Blocks of buildings (object shape devoid of finishes) are characterized by such dimensions as to be achievable within these physical models.

The level of detail is then characterized by a series of predominantly regular elements, homogeneous, on which textures and other details are not shown because they are too small dimensions. The goal of these maquettes, is not in fact the yield of objects in terms of realism, but rather to give a return of **forms** and their relationships.

Image	Building / BuildingPart	WallSurface / RoofSurface	Openings	City furniture	Vegetation / Plant Cover
	Multi Surface Repr. Surface Repr. Point Repr. Prismatic blocks model with vertical or horizontal boundary. Height/Footprint accuracy: > objects 6x6 / 3 (m^2 / m)	Surface Repr. Horizontal roof, vertical surfaces or unique height (maquette flat)			Solid Repr. Surface Repr. Solitary vegetation > 12 m Plant cover > 5ºx5º (m^2)

As already described, the dimensions are reduced to the point that it can not accurately represent objects below certain measures, and the roofs are approximated as flat roofs; what is referred to are basically the volumes (of buildings but also include landmarks in case they fall within the tolerance of the size) and single vegetation that has a minimum of 12 m in height. Representing objects below a certain size would be of little significance at this level of scale.

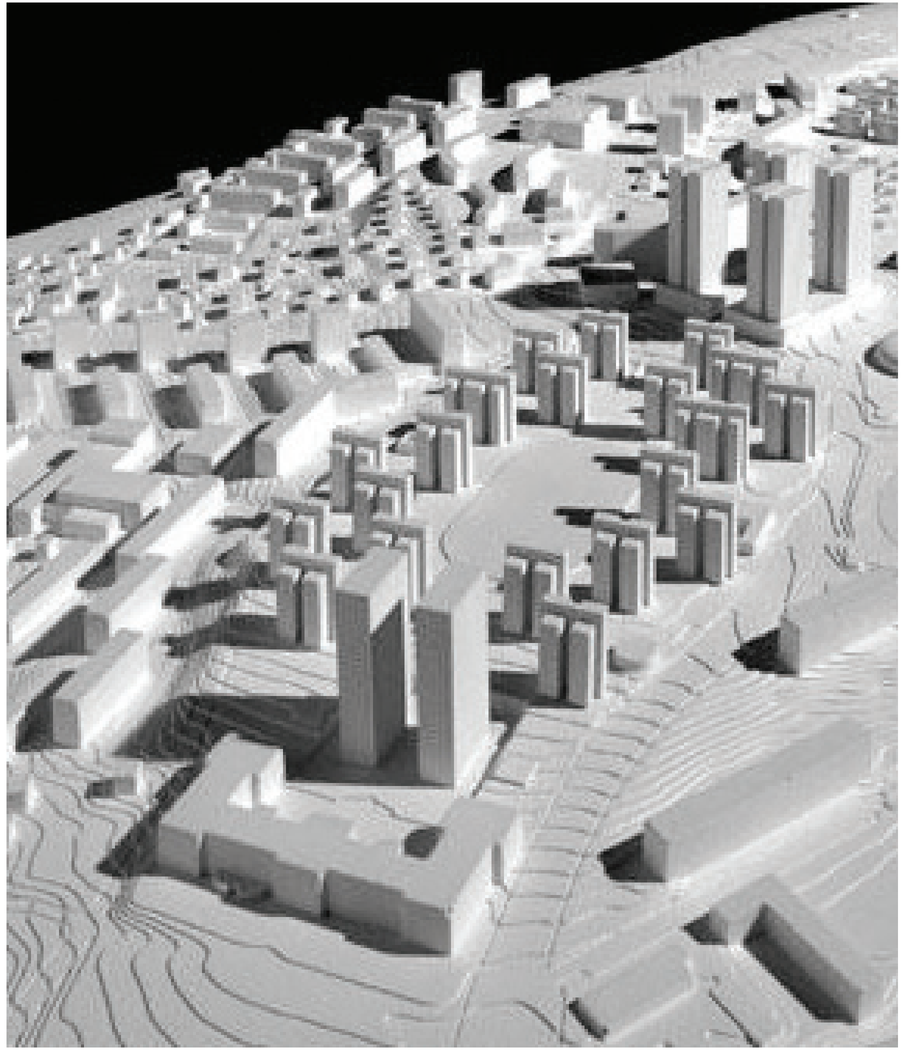


Fig.5.4 Example of LoD 1 M Maquette scale 1: 1000 | Eco-quartiere a Losanna (Monestiroli Associati) 1:1000

M LOD 2 STRUCTURE

Viewing some details become possible in level of detail 2, which is identified with a scale <1: 500. This probably represents the most significant step with regard to the insertion of the details within a maquette. As mentioned in the brief definition in the table, the facades of the blocks become themed, with the addition of texture or detail on the facade.

For example, the technique often used in this type of model is the application of facade images on building blocks (images obtained by composing multiple photos via Autopano software); during a visual simulation, this will greatly affect the final result, which will be far more realistic than a monothematic facade. Another solution, which may be less effective, consist in laser cutting façade (e.g. carved windows/doors) because this kind of mock-up are basically realized with one single material (e.g. wood), due to this you lose the sense of different materials , and therefore the visual perception of the model moves away from the realistic concept. The choice of a particular technique is determined by the type of simulation in which the maquette represents the primary support element.

Image	Building / BuildingPart	WallSurface / RoofSurface	Openings	City furniture	Vegetation / Plant Cover
	Solid Repr. Multi Surface Repr. Prismatic blocks model with thematically differentiated surfaces, optional roof overhangs. Height/Footprint accuracy: > objects 4x4 / 2 (m^2 / m)	Multi Surface Repr. Surface Repr. Generalized roof type and orientation; thematized vertical boundary (with images or lasercut)	Surface Repr. Printed openings	Multi Surface Repr. Multi Curve Repr. Point Repr. Prototypes, Vehicles, people, fences, banches. Detailde ground surface.	Solid Repr. Solitary Vegetation > 6 m

They can also represent smaller objects (4x4 / 2 m), the accuracy of the urban structure increasingly reaches more precise that approach the faithful reproduction of reality; also architectural elements such as walls and fences may begin to appear (if of a size such as to be considered) and vegetation with a minimum height of 6 meters within these mock-ups. Textures, as already mentioned, their theme building facades and flooring. Urban simulation held by the Urban Simulation Laboratory Fausto Curti on the draft Garibaldi Repubblica using a physical model that falls into the category M LoD 2 (Fig. 5.5).

Fig.5.5 Garibaldi Repubblica 1:500 | laboratorio di simulazione urbana Fausto Curti Politecnico di Milano

M LOD 3 SURFACE

It is denoted by the description corresponding to the LOD 3 reported by CityGML specifications (Gerhard Gröger, 2007), since the level of detail has reached an accuracy that you can view inside the maquette most of the elements, both architectural and decorative.

The dimensions indicated by the identification scale <1: 200 in fact allow the use not only of the textures (both for facades for flooring), but also of architectural finishes as is visible for the palisades in Fig. 4 present within the model of via Celoria scale 1: 200 made within the Urban Simulation Laboratory of the Politecnico di Milano.

The choice of materials for the construction of the maquette is fundamental for the good performance of the simulation; the exploitation of scale makes possible the use of more specific materials and more targeted in such a way that visually, the physical model is more close to reality than previous levels of detail.

Image	Building / BuildingPart	WallSurface / RoofSurface	Openings	City furniture	Vegetation / Plant Cover
	Solid Repr. Multi Surface Repr. Multi Curve Repr. Denotes architectural models with balconies, overhangs, bays ect... Choise of specific materials for objects. Height/Footprint accuracy: > objects 2x2 / 1 (m^2 / m)	Multi Surface Repr. Surface Repr. Detailed walls and roof structures with real object form.	Multi Surface Repr. Real object form	Multi Surface Repr. Multi Curve Repr. Solid Repr. Real object form; vehicles, people, fences, banches. Use of specific material for each element Detailde ground surface.	Solid Repr. Solitary vegetation > 2 m

Fig. 5.6 - Via Celoria maquette scale 1:200 | Laboratorio di simulazione urbana Fausto Curti Politecnico di Milano

The surface, which could be from two-dimensional images of the facades, or the reconstruction of the pavement, become three-dimensional and are also themed further thanks to different materials. The inclusion of other elements of the street furniture (chairs, cars, people etc ...) give an added value to the physical model and its efficacy in simulations; the natural elements can be represented in their real form, with a limitation on the minimum size (ref. example scaled object).
This is the highest level of detail considered for a street level representation, which is the most important for urban design and planning projects.

The image portrays the via Celoria model with the implementation of the new project (Fig 5.6) during the spring festival of the Faculty of Agriculture (UNIMI), during which the maquette was used as a learning tool, which allowed the citizens and students of the neighborhood to observe the new project more closely, supported by 3D views presented in virtual reality using cardboard, fostering in them a more significant involvement than mere consultation of plants and traditional prospects. The same procedure was tested again also in meeting through citizens and the municipality of Zona 3 in Milan (2016).

M LOD 4 DETAIL

This category of maquettes is considered the completion of the previous level with addition of more **details**, including every object, interiors of the buildings in their real form. Each characteristic of the physical model, and all the elements that compose it, can have a three-dimensional structure and very close to reality.

The dimensions indicated by the identification scale <1: 200 in fact allow the use not only of the textures (both for facades for flooring), but also of architectural finishes as is visible for the palisades in Fig. 4 present within the model of via Celoria scale 1: 200 made within the Urban Simulation Laboratory of the Politecnico di Milano.

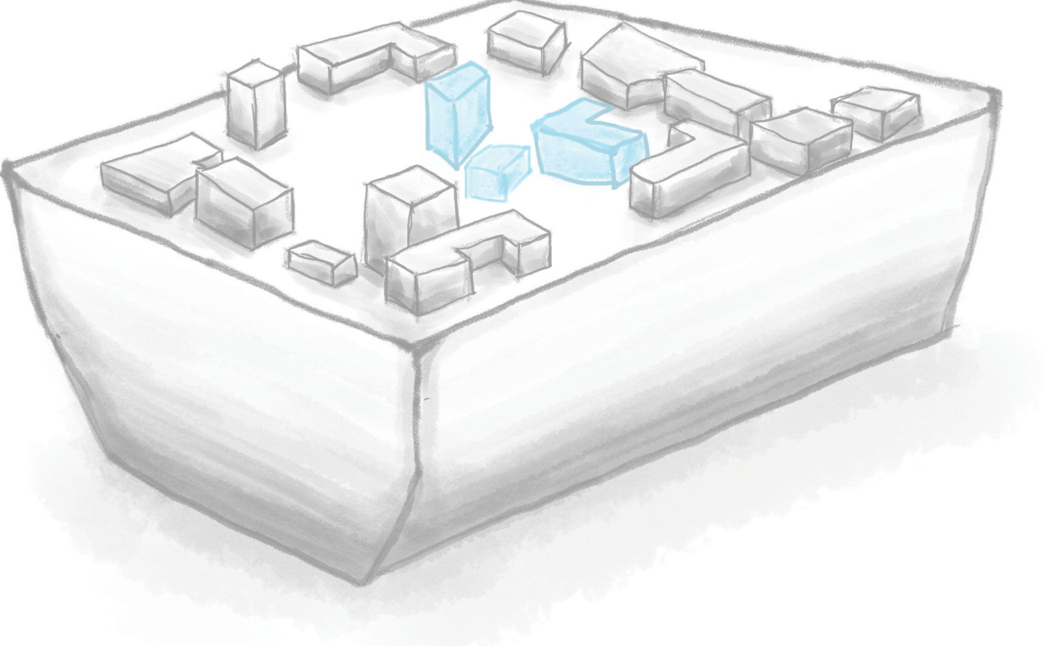
The choice of materials for the construction of the maquette is fundamental for the good performance of the simulation; the exploitation of scale makes possible the use of more specific materials and more targeted in such a way that visually, the physical model is more close to reality than previous levels of detail.

Image	Building / BuildingPart	WallSurface / RoofSurface	Openings	City furniture	Vegetation / Plant Cover
	Solid Repr. Multi Surface Repr. Multi Curve Repr. Completes a LoD 3 model adding interior structures for 3D objects	Multi Surface Repr. Surface Repr. External shell could be from LoD 1 M to LoD 3 M	Multi Surface Repr. Real object form	Multi Surface Repr. Multi Curve Repr. Solid Repr. Real object form, interior details	Solid Repr. < Lod 2 M

Fig.5.7 architecture interior model | Copyright: ONEOFF

This level of detail requires an important observation, namely, the decision to keep it as a level of detail in itself : in the previous chapter, the new CityGML LoD concept considers this level of detail differently, separating it from the others; because under the geometrical aspect, inside the digital domain, the representation scale of the objects is 1:1, so interiors can be represented regardless of shell's level of detail; and even in the semantic context, where LoD 4 has its own semantic levels, from LoD Interior 0 to LoD Interior 4 (Benner, 2013).

However, since we are no longer in the digital field, but we have moved in the physical one, is better to take into account the M LoD for some main reasons: first, the semantic classification is no longer feasible as much as in the digital field, especially a subclass of the ***interiors***, and second, all the architectural models with a scale < 1:50 are dedicated to interior models, and so the choice to keep these LoD is mainly maintained for this.
All features represented in this kind of maquette, should be represented exactly as in its real dimensions; not only forms, but also materials could be the same, both interiors and the external part (street level). As mentioned before, M LoD 4 is dedicated only for architectural models just because for urban projects, the previous level of detail for disposition/arrangements (M LoD 3) is enough since we usually don't need knowledge regarding the interior of buildings.



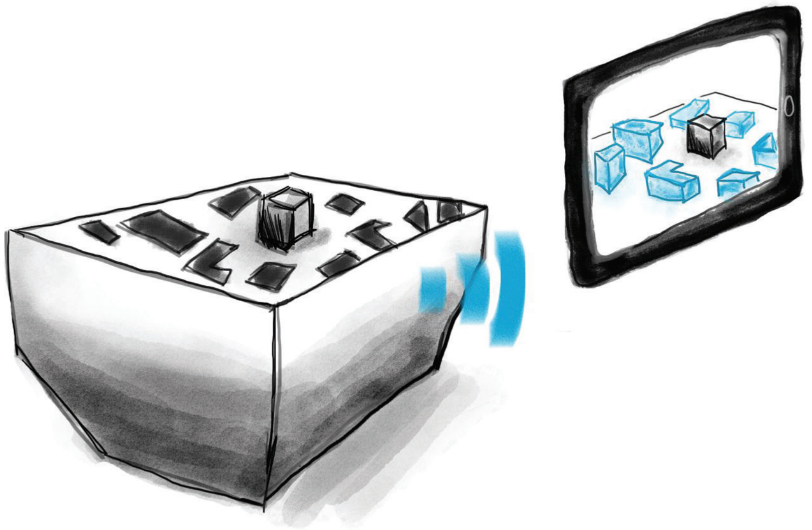
05

APPLICATION OF TOOLS AND TECHNIQUES ON PHYSICAL MODELS

As explained in the previous chapter, Augmented Reality applications available today on the market are not designed specifically for augmenting physical models (named here *Augmented Maquette*, Fig.6.1). It is then necessary to use applications designed for indoor or outdoor AR and – improperly – apply them to physical models. It is also necessary to develop an analysis about some problematics related to this adaptations considering different aspects like the fluidity, stability of the visualization, and so on.

Doing one step further, application of AR tools currently available to us on a maquette, and the development of some hypothetical scenarios considering also the development of technologies will be analyzed and discussed in order to obtain a sufficiently effective mix.

Fig.6.1 Example of augmentation of physical model through a digital device such as a tablet | copyright: the author



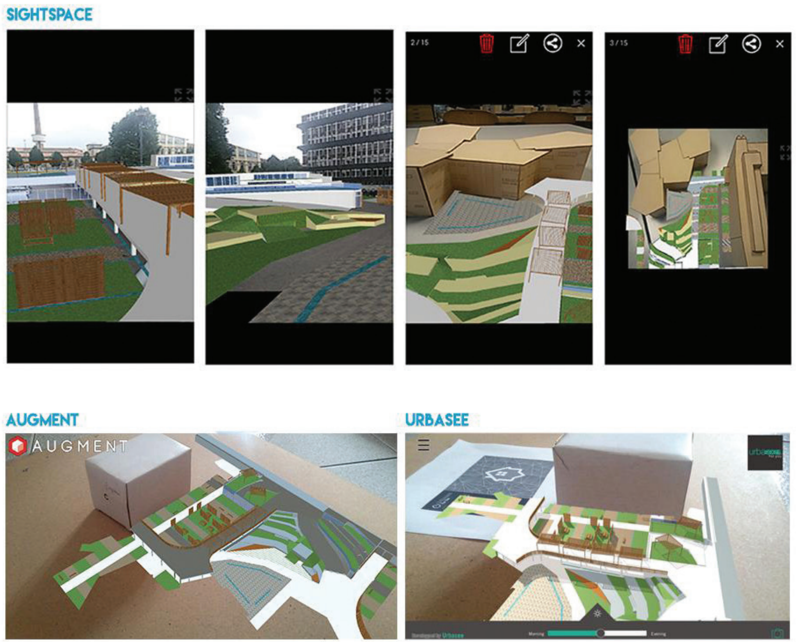
5.1 ANALYSIS OF AUGMENTED REALITY APPS

Pictures inside the matrix (Fig.6.2) show some examples of tests and experiments performed with selected apps as tests: the digital 3D model's project was the final project of master's studio in *Architectural and Urban Simulation* - prof. B. Piga and R. Salerno, where students had to redesign the area in front of Trifoglio building of Politecnico di Milano; this was a main topic about the project *"Città Studi Campus Sostenibile"* promoted by POLIMI and UNIMI (started in 2011) to transform the university district into a Campus and part of a city that becomes a model for quality of life and environmental sustainability through the active contribution of the entire university population and residents of the neighborhood.

Inside pictures taken directly from apps (right part), there are different uses of devices, both outdoor and in-vitro in order to investigate the technical issue as already explained; for instance, it is possible to simulate and test design project in 1:1 scale on-site, hence with a subjective view, or it is likewise possible to augment physical models with digital layers. The digital 3D model uploaded inside different apps is the same, so all outcome's differences vary due to hardware/software characteristics.

1 - LOW 2 - MEDIUM 3 - HIGH	Stability	Responsiveness	Texturing	HMD	Markerless
SIGHTSPACE					
OUTDOOR	2	1	2	VR only	✓
MAQUETTE	1	1	2	VR only	
AUGMENT					
OUTDOOR	3	3	2	-	✓
MAQUETTE	2	3	2	-	
URBASEE					
OUTDOOR	2	2	3	-	✗
MAQUETTE	1	1	3	-	

Fig. 6.2 The matrix shows the results of a comparative analysis between the three mobile Augmented Reality applications under investigation: SightSpace, Augment, Urbasee. The right side of the image presents the qualitative results of the study: for each app a comparison between outdoor and indoor performances was conducted according to stability,



Some screenshots taken from device smartphone Samsung Galaxy S3 Neoboth outdoor and applied on physical model.

responsiveness, texturing, Head Mounted Display, markerless option. If read together the matrix allows a comparison between the three applications. On the left side of the image it is possible to visualize some screenshot of the testing phase: the first to images (up-left) refer to outdoor Augmented Reality, while all the other to in-vitro Augmented Maquette | credits: the Author

The following text explains exactly the meaning of technical issues considered for the comparison between different apps (B.Piga, V. Petri, 2017):

“In order to investigate and find out the solution, three Apps that seemed to be the most suitable for our purposes were been selected from a wider list, namely: SightSpace by Limitless Computing Inc., Augment, and Urbasee by Artefacto. A qualitative analysis of the apps has been performed comparing their performances in outdoor environment with the ones with a physical scaled model of the same area; the analysis was developed investigating the following technical issues: Stability, Responsiveness, Texturing, HMD – Head Mounted Display, Markerless option. More in detail:

Stability: level of steadiness and alignment of the 3D model to its location in the real world. In particular, the digital model should remain stable and with a low rate of flickering at its location and correctly collimate to the real context even when the user is moving around. This is related to the Tracking System Delay that is the “time [needed] to measure the position and orientation of the user’s head” together with the Image Generation Delay, that is the “time for the graphics engine to generate the resulting picture”

- *Responsiveness: the degree of real time reaction of the virtual environment when a rotation/move/zoom command is input. This is linked to the Image Generation Delay.*
- *Texturing: the render quality of the texture of the model.*

- *HMD: when the app allows to visualize the model with a simple Head Mounted Display this issue assesses the responsiveness of the app to the navigation with such a device. This is important because in case of slow synchronization - namely latency - between the movement of the user and the relative movement of the scene, this delay often provokes nausea and discomfort. This is linked to the Display System Delay, that is "the time required to display the image in the Head Mounted Display.*
- *Markerless: this issue simply says if the app can work without a Fiducial Marker as a reference for correctly locating the model in the real context. Apps that do not need this reference are classified as markerless; these generally locate the model according to the geo-spatial localization of the user for on-site navigation, or thanks to beacons, or 3D scanning\tracking and recognition of the environment and its elements (i.e. computer vision: image recognition and 3D object tracking)."*

(B.Piga, V. Petri, 2017)

In the upper part (left) there's the legend regarding classification of stats which are used to create the qualitative study: 1 for **low**, 2 for **medium** and 3 for **high**; since there is no a proven method before for this kind of evaluation, the app that will show the worst or poorest feature *will be shown with the lowest value, while the best performance will have the highest score*. Moreover, HMD and Markerless features don't have a score, but just an indication about regarding their presence within the app's functions.

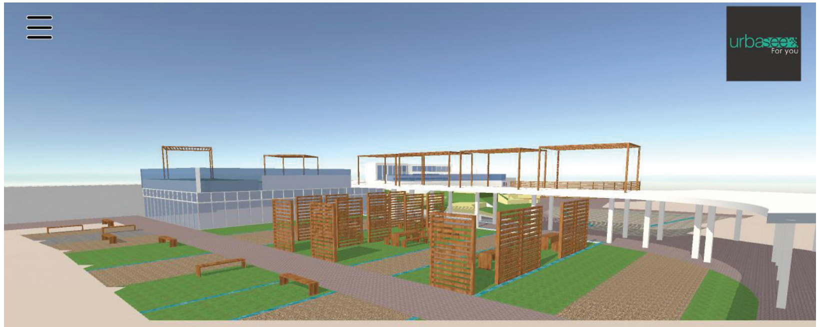
Through information derived from the matrix some problems arise, but also potentialities which can be exploited for the benefit of the augmented maquette.

One of the first behavior that arise from the analysis is that apps work better in real environment than with scaled models. This is why they are not designed for that, and so the reduction of the virtual 3D model to the scale of the physical mockup generally generates some problems in the correct functioning of the apps, even if by modifying and simplifying the 3D model the problematics can be partially overcome.

For instance, if we look at the table we can notice that SightSpace works well for outdoor AR, but it loses stability when it works with scaled 3D models. SightSpace is also the only app, among the studied ones, that allows to use HMDs (Head Mounted Device, fig 6.3.1) at this time, but with Virtual Reality mode only (Fig.6.3), which is a very powerful simulation tool but that deviates from the study on AM.

Fig.6.3 BELOW *example of Virtual Reality Tour inside Urbasee by Artefacto*

Fig 6.3.1 *Head Mounted Device* | Samsung Gear VR



Lack of an HDM support for the Augmented Reality feature is very represents a serious problem for AM solutions, since it is of course crucial for a ***two hands*** interaction with the physical models, and make the experience more functional; this consideration will lead to the development of one of the possible augmented maquette's scenario.

Both SightSpace and Augment provide markerless solution that allow to resize, rotate and move the model on the screen; otherwise there is the opposite situation, that we find in Urbasee, that is, the need to insert a physical marker into the mockup (Fig.6.4), making possible only the different sizing; to rotate or move the digital element you will need to perform those actions by moving the marker "physically" and at our discretion inside the maquette. Stability and Responsiveness in Augment remain excellent in outdoor and on maquettes; the stability remains quite good even when moving the device.

In a recent app implementation, the quality of texturing increased a lot, even if this is still not optimal.

In a previous version of Augment for instance, the texture was very low (dull colors, unrealistic texture etc…). The quality of texturing is instead excellent in Urbasee, that assures the more realistic outcome among the three, but unfortunately today, using Urbasee for augmenting scaled models is still not efficient, also due to the ***low stability*** of the digital model and the ***low responsiveness***, in fact the app does not follows the movement of the device in a congruent and fluid way.

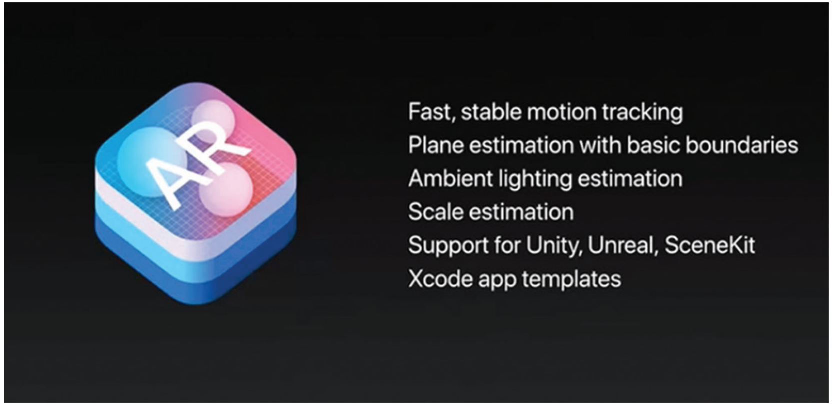
Fig.6.4 Inside the photo there are 3 elements: the digital model a physical block and the marker (paper). If the camera miss the marker, the 3D model disappear.

Between the three apps, *Augment* is the one that better fits the requirements for AM, but in general, ***stability and responsiveness*** are too low in all the app tested, while the quality of texturing can lead to medium\high results. Unfortunately, this parameter alone is not enough for a correct usage of AM for urban design purposes; all the aspects considered are important and relevant at the same level in order to obtain a good result.

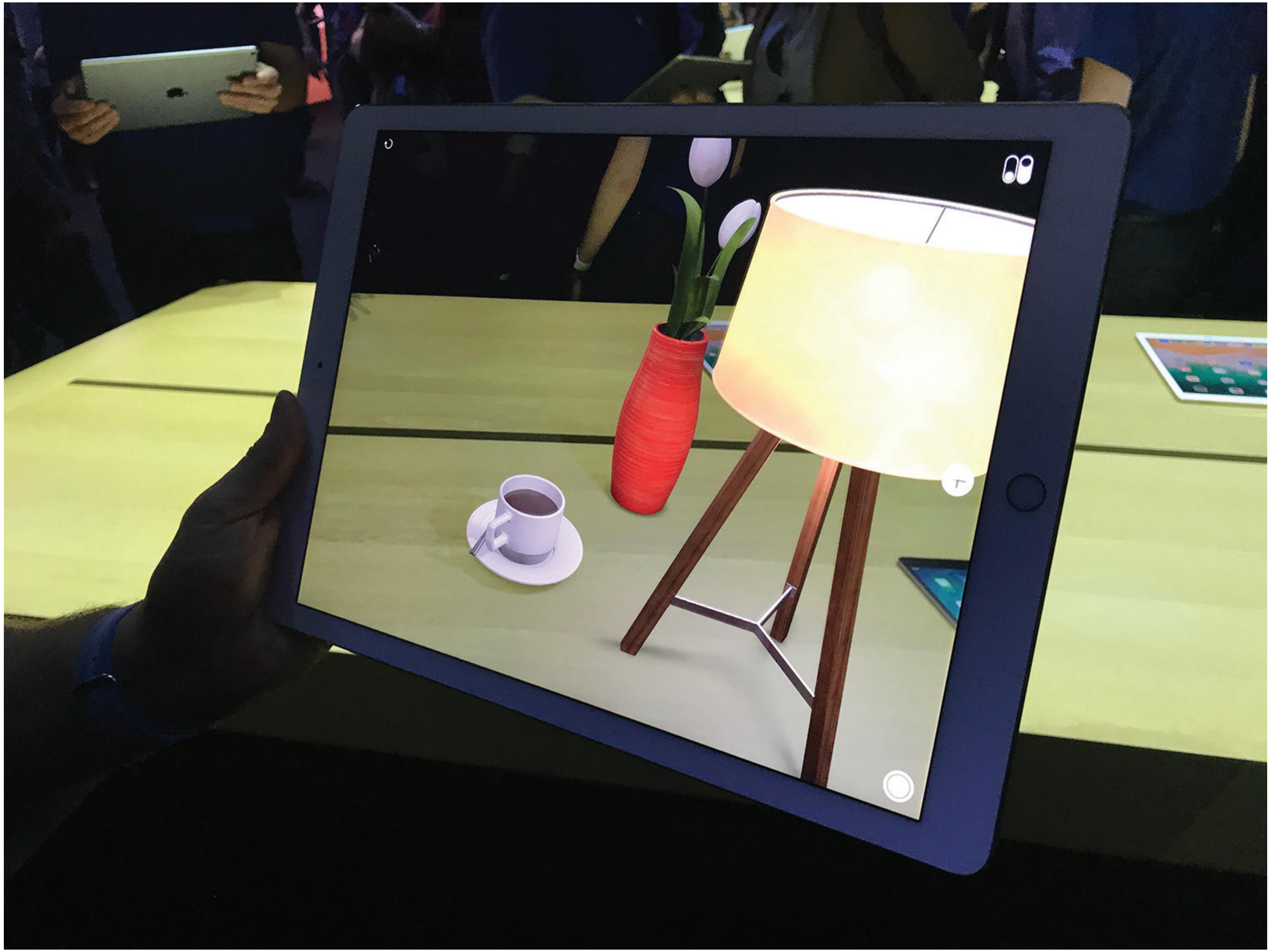
In conclusion, the comparative analysis of the apps, shows that the development of the ***software for Augmented Maquette still need some relevant development for a proposer application in the architectural field***. It is in any case important to notice that along the research process we tested the apps several times and in any new release the improvements done for AR were useful for AM as well.

In the next paragraph, the author will come up with a series of considerations regarding technical issues related to limitations of apps, so which kind of digital elements can be projected on the scale models as layers with these conditions, tools, considering M LoD defined in the previous chapter and finally, how we can overcome problematics with the support of future technologies combined in mixed solutions.

Demonstrating that the field of augmented reality is always developing through new advanced technologies under the hardware and software aspect, there was Apple's presentation at WWDC (worldwide developers conference) on June 5, 2017, last month, their *ARKit* (Fig 7), a platform for Augmented Reality experiances.



As shown in the figure, the caracters and parameters of this new apple platform, usable through their smartphones and their iPad, mirror some of the aforementioned ones, such as surfacing, and what has been shown to the public so far, The potential is enormously above expectations.
Stability, high quality textures, the markerless system, and even interaction between the same objects, such as generating shadows if one of the virtual objects has a light source (visible in the image of the next page) makes it clear how We approach more and more to the personal augmented reality..



Demostration of Apple's ARKit at WWDC (June 2017)
https://www.cnet.com/news/apples-first-crack-at-ar-looks-surprisingly-good/

5 . 2 IMPLEMENTATION OF AUGMENTED REALITY ON PHYSICAL MODELS: MIXED-REALITY URBAN DESIGN

This process of implementation of AR on physical models represents what we have defined as *Mixed-reality Urban Design* (Fig. 6.5) where mixed-reality means *"anywhere between the extrema of the virtuality continuum, where the virtuality continuum extends from the completely real through to the completely virtual environment with augmented reality and augmented virtuality ranging between."* (P.Milgram et al, 1994); this design process represents an innovative approach with the use of new technologies. In the following section, after the research on apps, the author will find out which are the main issues that affect the tools we have at our disposal today and how to use it best with the support of the framework for model categories (M LoD).

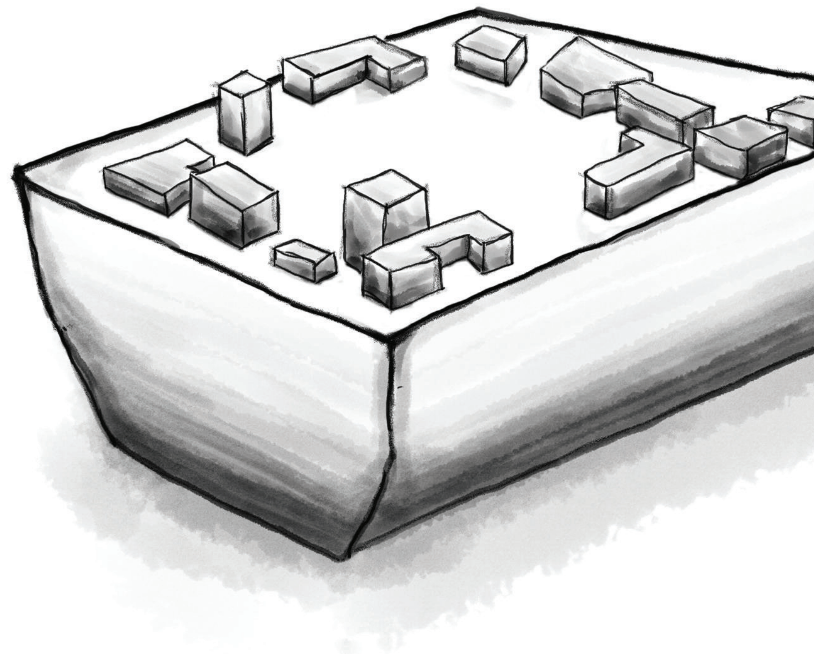
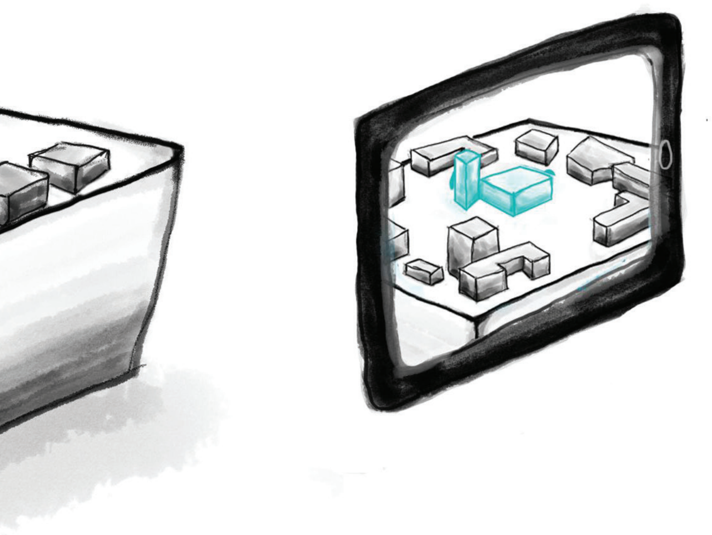


Fig. 6.5 Concept of Mixed-Reality Urban Design

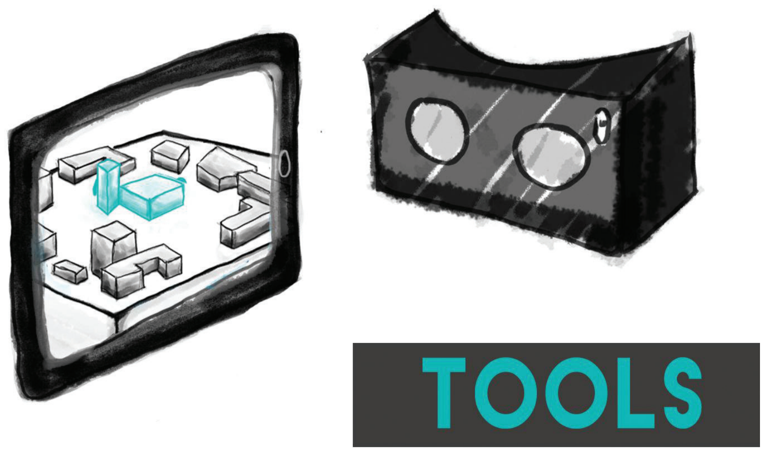


Following the study and the analysis of the applications, the author can finally consider some of the problems encountered and a relative possible solution to overcome them; in fact, some types of elements, with the technology at our disposal, are not well suited to being projected onto a maquette. At the same time, it is necessary to expose together with the problems, including a specification on the typologies of digital informative layers.

MIXED-REALITY URBAN DESIGN

5 . 2 . 1 ADAPTATION DEFECTS OF DIGITAL INFORMATIVE

First of all, it is important to specify that the apps studied are designed to be commonly used with tools such as smartphones, tablets, cardboards (Fig. 6.6)



- The use of a device requires the **use of hands**, so keeping them occupied: this makes it difficult to use the AR.
The solution use a type of HMD (head mounted device) type such as cardboard. But as already seen in app analysis, cardboard is currently not implemented, or remains the exclusive use of Virtual Reality.

- The AR, by using a **markerless system**, the use of hands to resize, move and rotate the model gives much more freedom of interaction with the model itself, But as it derives from qualitative analysis of APPs, often the digital layer is losing on stability and responsiveness, and therefore becomes difficult to handle the model (trembling, instability, ect). What could solve this problem could be solved with a system similar to the Marker, or the geo-localization in outdoor augmented reality (Fig 6.7), but which actually works more in the way of recognizing the edges of the physical model;

fig. 6.6 Tools used for Augmented Reality apps

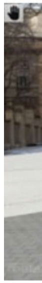
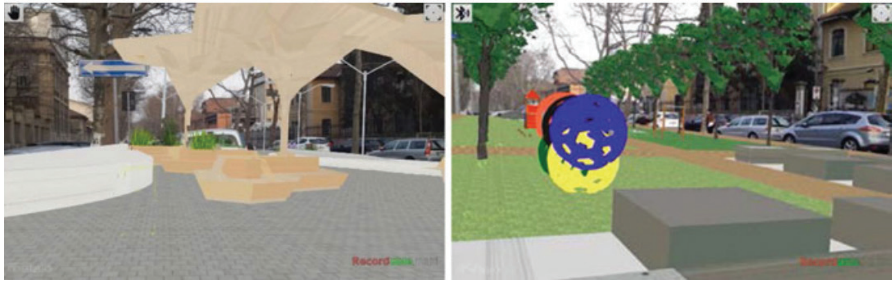
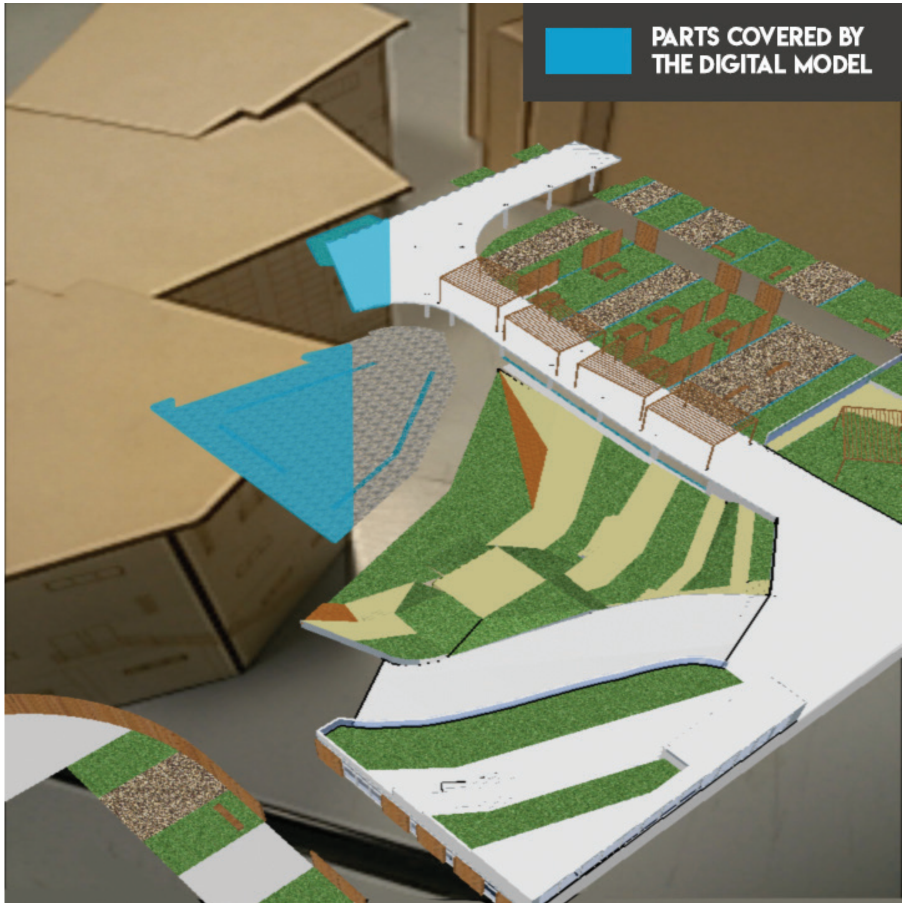


Fig 6.7 LEFT | augmentation of Via Celoria | Urban Design and representation (2017)

Fig 6.8 RIGHT | Technical problem related to overlapping between digital and physical

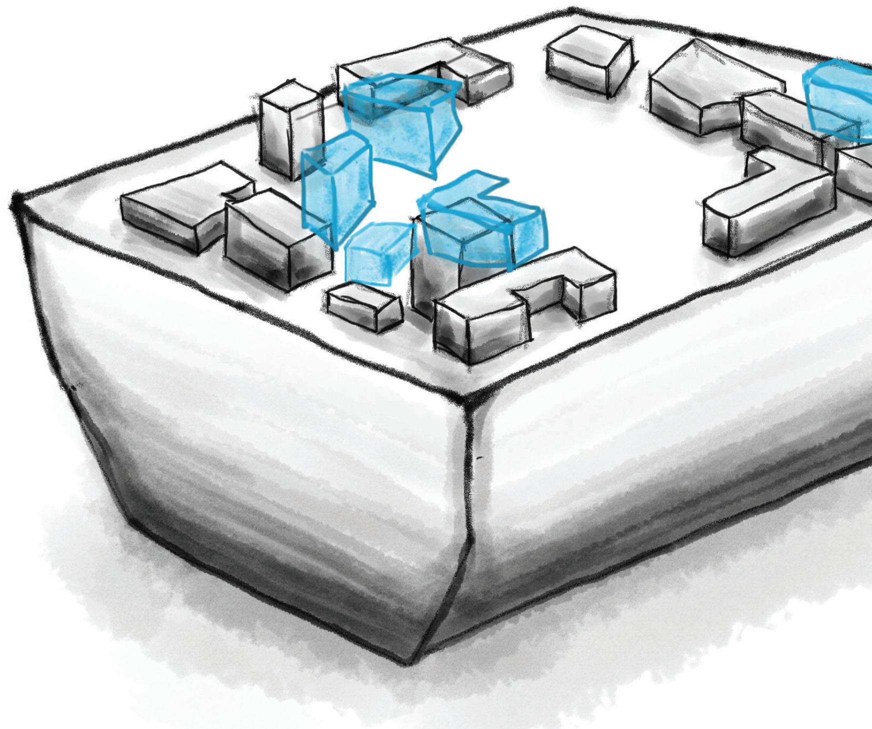




It remembers somehow the functioning of the luminous planning table but remains more flexible, so as to hook it up like markers (a system hypothesized for Matsuda's hyper-reality), but without the latter on the model, keeping the clean mock-up.

- This consideration brings us to a third problem, one of the most important issue related the previous fact: the ability to detect the physical edges of the model would also be useful to erase the digital model parts that overlap, creating a less realistic effect (Fig 6.8); this type of sensor already exists but is not implemented in AR applications. Of course, creating an application that makes this possible, will surely be a solution to this type of problem.

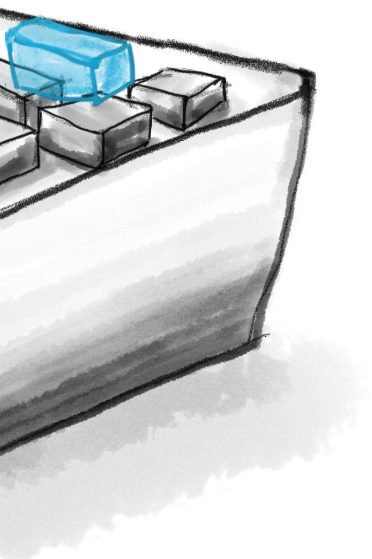
6.9 COMPLEX DIGITAL INFORMATIVE CAN GENERATE OVERLAPS



- This leads the author to claim a further technical defect due to the fact that these apps are not designed to be used in an in vitro context: too large and complex digital elements (such as those used for apps, “trifoglio area”) are not well suited to adapting to the maquette; the reasons for this statement are those listed earlier. For instance, as shown in picture 6.9, having both complex scaled model and a huge digital model, can generate many overlaps.

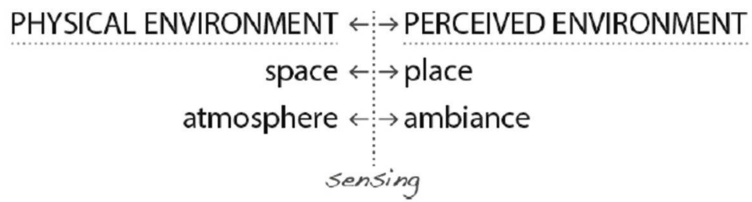
In the current technological situation, the best solutions are 2: the first, simplest, is to choose to project on the maquette elements that are simpler and less articulated; The second, more comical but more thoroughly analyzed by the author, is the choice of digital elements (size, type, etc.) depending on the level of detail that will come up for the scaled model.

In the last chapter, the author will summarize these statements in a list of features that a good app should have to meet the needs of an augmented maquette really effective.



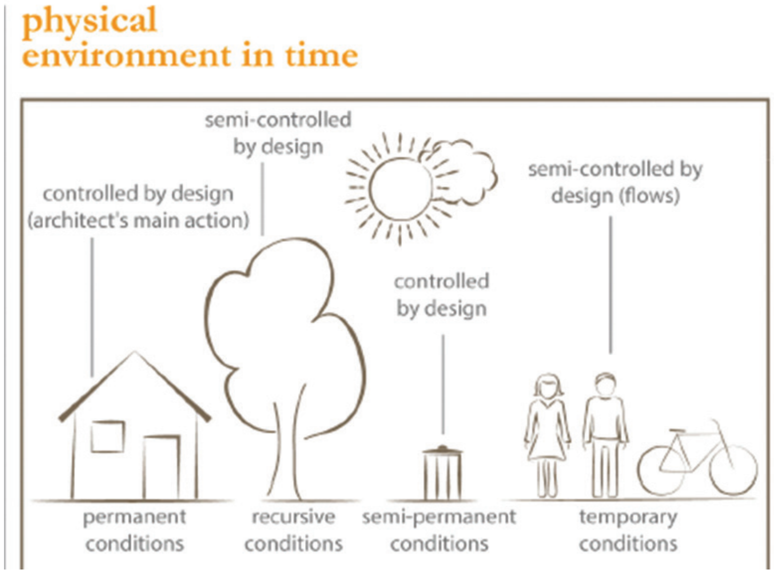
5 . 2 . 2 DIGITAL INFORMATIVE LAYERS

In this paragraph, the author will describe which types of elements can be projected on the scaled model and the latter relate directly to the various M LoD.
Digital informatives can also be considered inside (i) physical environment or (ii) perceived environment (Piga & Morello 2015).



6.10 Physical vs Perceived environment | Source and Copyright: “Environmental design studies on perception and simulation: an urban design approach” Piga & Morello 2015

6.11 Source and Copyright: “Environmental design studies on perception and simulation: an urban design approach”
Piga and Morello 2015



In the first case, we talk about everything that is closely related to the physical features which contributes to create a physical identity of a space; the second one is more related to the “personal sphere”, so how people perceived a place depending on his emotions, experience, ect. What concerns the subject directly is what is called the “physical environment in time” (Fig 6.11); extracting from the multisensory concept of perception, this picture shows in a very clear way, which are components of physical world, and therefore the key elements for defining our digital information.

Important to note among these elements is what can be physically and practically implemented, and what is more suited to be projected through augmented reality: temporary conditions (such as Flows) fall into latter category, recursive and semi-permanent conditions they are much more suitable to be included in the physical model.

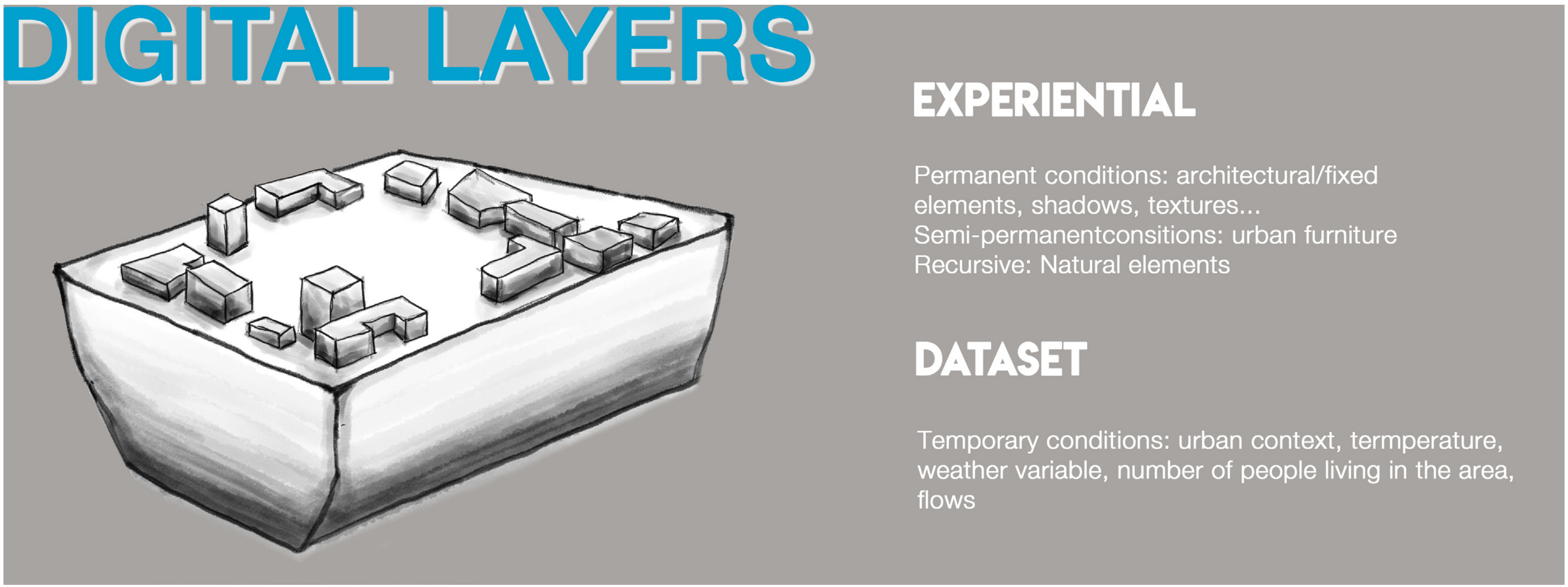
In addition to the aforementioned categories, the author adds further clarification regarding the typologies; the following abstract taken from the EAEA13 conference paper by the author and professor B.Piga gives an important introduction about this topic:

[...] "Two main typology of digital informative layers (data) can be summarized in 2 cases: (i) experiential (ii) dataset. In the first case, it is possible to outfit the model with data that contributes to render the situation as it would be perceived in reality, e.g. shadows, people, textures and so on; in the second case the augmentation can show information related to the urban context, such as temperature or other weather variable, information regarding the number of people living the area, and similar. While in the first case we are in the range of experiential simulation, in the second one we enter the domain of conceptual simulation.

The combination of real and virtual elements can of course work with indoor and outdoor Augmented Reality, but also for Augmented Marquette. In this case, the information can be shown dynamically by a projection on the surfaces of models, as for the Luminous Planning Table - designed at Massachusetts Institute of Technology in the late nineties- and similar tools, or through devices, such as tablet or Head Mounted Displays" [...]

As shown in the figure (Fig 6.12), the types of digital layers possibly projected on the maquette were defined. In the following text we will look in a more concrete way as these “families” of data relate optimally to the mockup.

Fig 6.12 Typologies of digital layers that can be projected on a scaled model | copyright the author

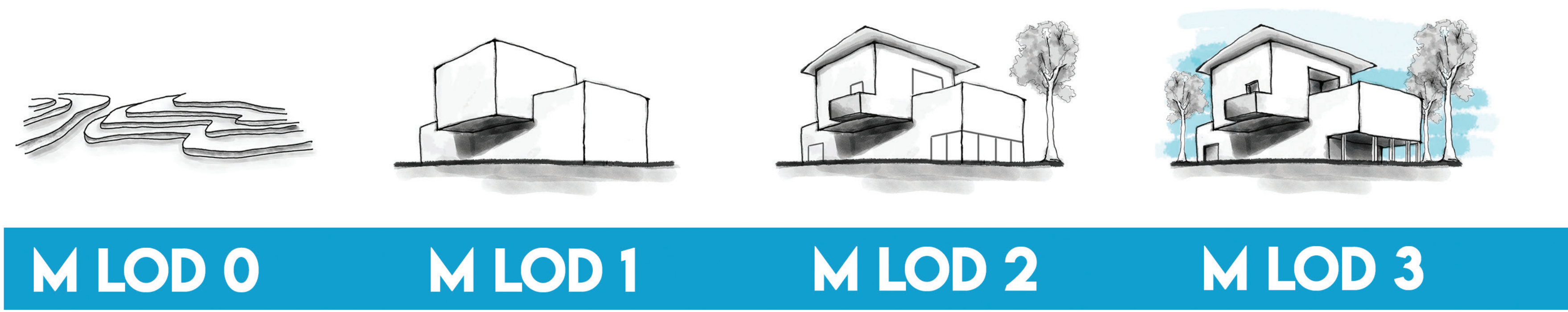


5 . 2 . 3 THE RELATION BETWEEN SCALED MODEL AND DIGITAL FEATURES

This paragraph is the last piece that will compile the final result of the studies carried out, that is, the tools and a framework of guidelines for the optimal realization of *mixed-reality urban design* which represents one of the ultimate urban simulation projected towards the future.

During the course of this thesis, the author defined the royalties and characteristics, more precisely the level of details of physical model as optimal support tool; Picture 6.13 illustrates the graphic return of M LoD. It is recalled that the level of detail concerning the interior of this study will not be considered taking into account that the author has concentrated most on *urban simulations*, which therefore affect the urban environment more at the street level.

LEVEL OF DETAILS MAQUETTE 6 . 13



Below will be given some indication of certain types of information that can be projected for each detail level category, but the decision remains arbitrary; The author in this case suggests which ones are the most suitable.

Many elements will be repeated; there will be a continuous add detail and some **M LoD** (realtes to “street level”) will have specific layers for their own categories.

M LOD 0

For sure, natural elements represents one of main layers projected on the scaled model: vegetation coverage, watercourses or water mirrors (e.g. for geomorphological studies); building complexes or urban context (e.g.block of buildings, very large buildings) being large-scale; new infrastructure (e.g. aqueducts, electrical installations, highways).
Many elements that make up new urban plans or projects in a large urban context: various types of flows (air currents, traffic flows, ...); Highlighting certain areas (soil use); indications on temperatures, indications of sources of pollution (acoustics, waste, etc.) with graphic return both point and area types

M LOD 1

Study the shadows of the urban context; In addition to people’s traffic flows, for instance, the new wind channels generated by the insertion of new architectural elements within the urban context (this type of simulation has already been used by the research group in the urban design platform); insertion of architectural projects at the “district” level, then new volumes; informative about public transport network

Information about activities (commercial, social, etc.) within a district, visible percentages of population data (quantity, age, employment, etc.), energy (consumption, production, infrastructure, duction etc.); Directions on particular buildings (residential, office, industrial, and so on)

M LOD 2

The addition of new urban elements, as previously defined semi-permanent, controlled by design, and temporary, partially controlled by design; Digital elements become more and more realistic and less schematic, so they conform to the model. Like the physical elements

of the model, the digital layers may have textures.
Urban furnitures, which are part of the semi-permanent layer category already mentioned, can finally fit into the model, both physically and projectionally (e.g. single vegetation, street lights, ect); this is because the size of the model allows it.
Regarding dataset layers, many of those already mentioned in the previous levels can be replicated in this type of physical model; It can, however, achieve more accurate accuracy on the location of certain services or infrastructures (e.g. bike / car sharing points), allowing in some cases to visualize them in their real form

M LOD 3

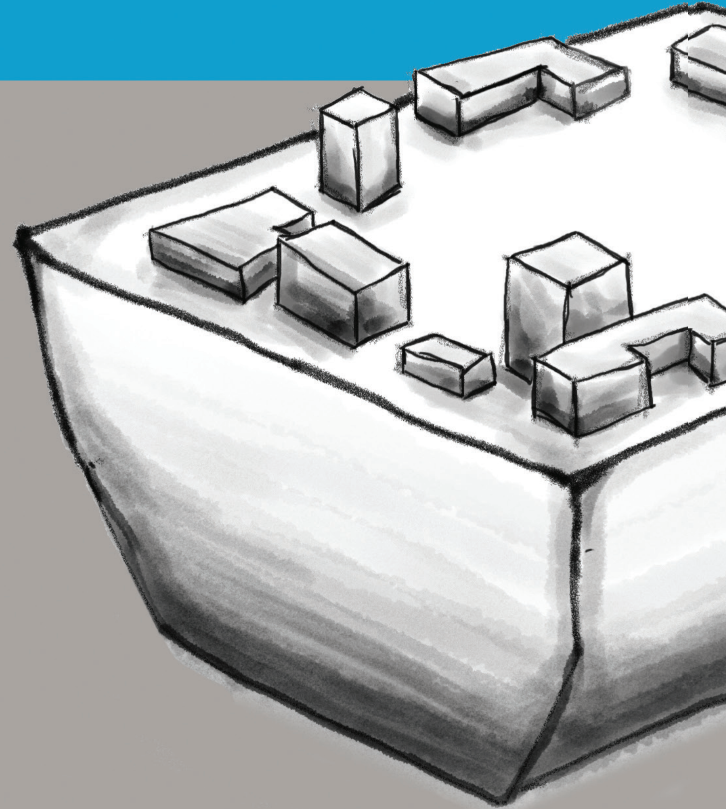
Once the maximum level of detail is reached, components that were schematic, such as traffic flows, or people, would go directly to their real shape (digital layers can be visible with well-defined people and vehicles);

To recall the discourse made on the semantics, if you first took into account percentage like pollution, or building function so far, one interesting information that can be readable on the model through digital layer projections, are for instance indications regarding percentage of opening, because it is more visible (This kind of information can also be shown in previous LoD but it will be less visible)

These features that have been grouped were finally selected as a result of comparative analyzes carried out by different specialist and researchers on various relative level of details of digital 3D models, and which are considered their standards too, to adapt and define new ones specific to physical models; a study relates to all the features and which are their typologies, what kind of error these features generate on the models with the current technologies at our disposal and then decide which types of elements can project on a physical model through increased reality and thus give rise to what has been defined by the author **Augmented Maquette.**

"Augmenting" a physical model with these features ensures a ***real-time*** cognitive addition to a physical object, which can be taped manually, ***displaying hidden information*** through virtual elements.

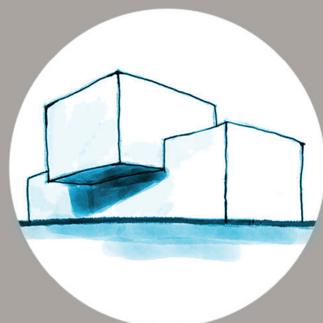
RELATION BETWEEN SCALED MODEL AND DIGITAL FEATURES



M LOD 0

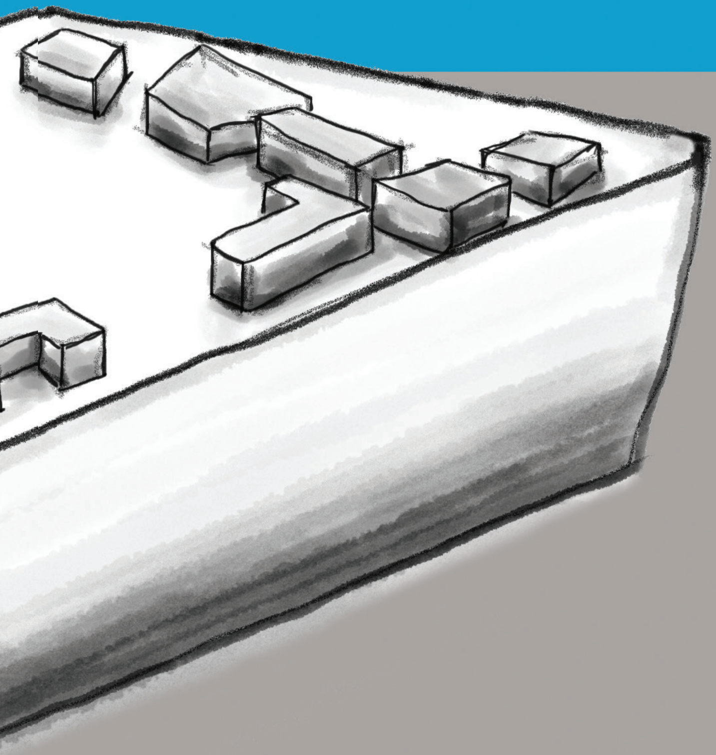
Natural elements: vegetation coverage, watercourses, water mirrors; building complexes, infrastructures (highways, electical installation.
Information about activities (commercial, social, etc.) within a district, visible percen tages of population data (quantity, age, employment, etc.), energy (consumption, production, infrastructure, etc.) Environment (noise pollution, smog level, etc.); Directions on particular buildings (residential, office, industrial)

Shadow study of the urban context; people's traffic flows, the new wind channels generated by the insertion of new architectural elements within the urban context; insertion of architectural projects at the "district" level, then new volumes; informative about public transport network.
Information about activities within a district, visible percentages of population’s data , energy (consumption, production, infrastructure, etc.) Environment pollution; buildings infos (residential, office, industrial, etc.)



M LOD 1

AUGMENTED MAQUETTE

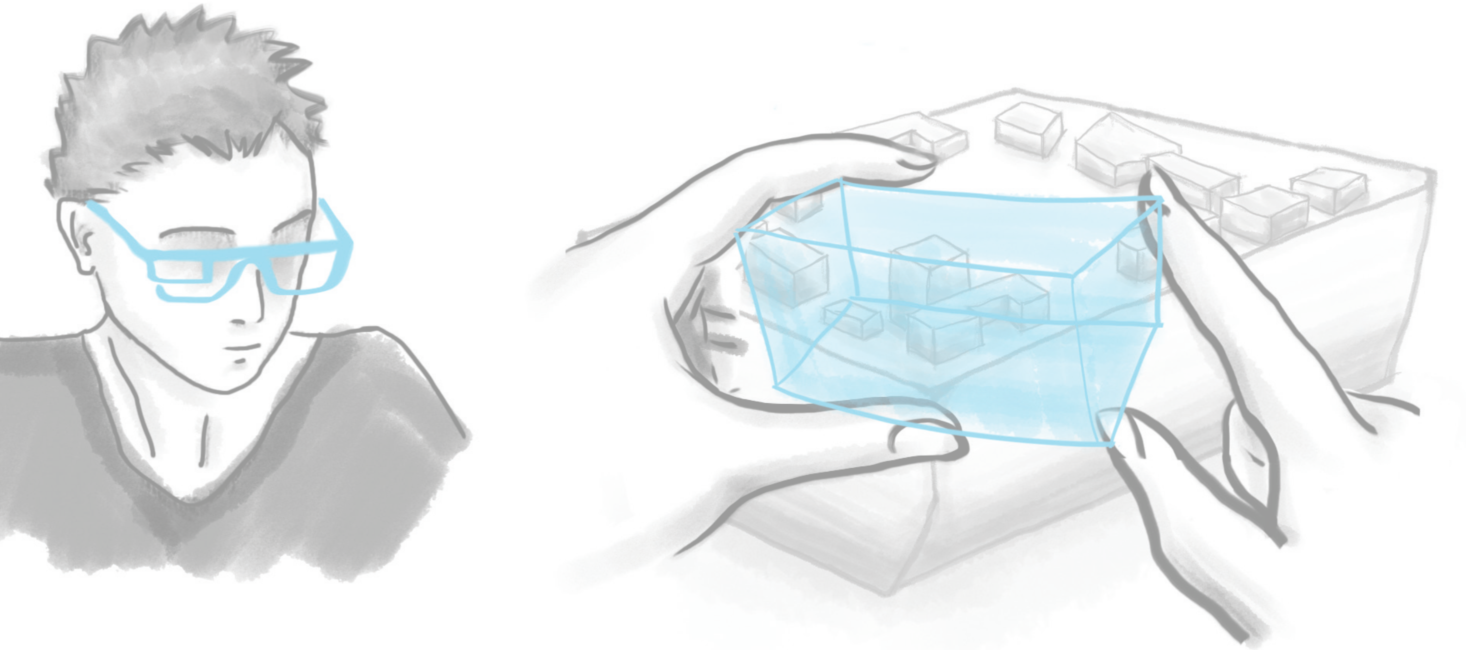


Semi-permanent, controlled by design, and temporary, partially controlled by design. Digital elements less schematic; the digital layers may have textures as physical ones. Urban furnitures, which are part of the semi-permanent layer category already mentioned, both physically and projectionally (e.g. single vegetation, street lights);
Dataset:

M LOD 2

Traffic flows, or people, would go directly to their real shape; To recall the discourse made on the semantics, one interesting information that can be readable on the model through digital layer projections, are for instance indications regarding percentage of opening, because it is more visible

M LOD 3



Mixed Reality for urban design is still far from being efficient and within reach in the urban design domain. Too many technological constraints are still limiting its applicability at the large scale and within all the different phases of design projects.

Before entering into the merit of public communication, the author wants to conclude the argument on the augmented maquette illustrating how this type of instrument and simulation can actually evolve simultaneously to the development of technologies in terms of AR.

First the author summarize what features should have the ideal app, based on the study carried out on them and the issues that have arisen adapting to the physical models (blue table).

These listed above were the main requirements that the augmented maquette would require for optimal operation, ensuring communication with evaluators, core components of the communication model (D.Appleyard, 1977), who receive the messages conveyed in the presentation of projects, include the planning commission or city council, their planning staff, and involved citizens: users, neighbors, or the general public; The use of this type of simulation, as analyzed in case studies, is not only used in presentations to public bodies or citizens, but also to students and researchers in the field of didactics.

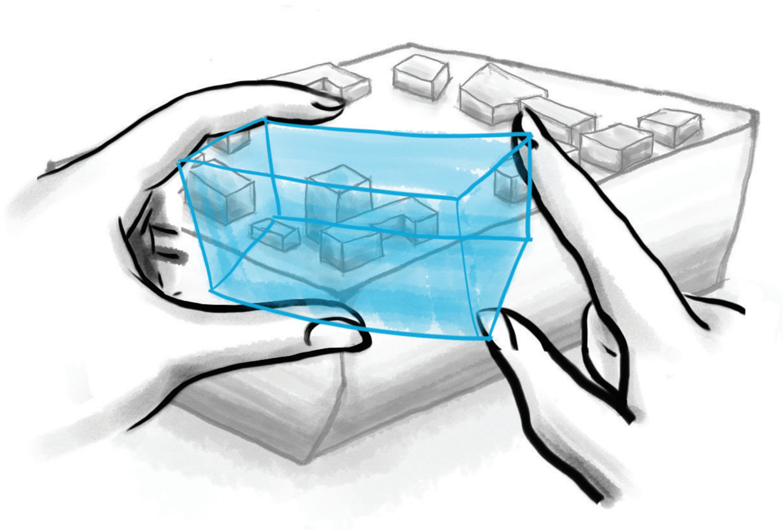
- **FREE HANDS**: dealing with interactive digital models, where using hands to rotate, resize, move, turn on or off layers, unconditional hands usage becomes a fundamental requirement
- **MARKERLESS**: Many apps currently (not just those studied) use the Marker Reading System, a system that has its pros and cons; On the one hand guarantees almost perfect stability, but on the other hand it would require the insertion of markers within the model, which would therefore “disturb” the effectiveness of the simulation.
- **POSSIBILITY TO GEO-LOCATE THE MODEL**: geo-locate the mockup in the real environment and then locating also the digital layers could ensure a fairly accurate localization, but without the use of markers
- **DETECT PHYSICAL EDGES**: useful to erase the digital model parts that overlap the physical one, also helping to position the model in place of the actual geolocation; changing position, the digital model will remain hooked to the mock up, thus fixing it even if the person moves around it
- **MASSIVE INTERACTION**: the user must have the freedom to interact with both the digital model via device, but in some cases also have the possibility to interact with the maquette.

5 . 3 SMART GLASS: THE AR WEARABLE TOOL

To better figure out a future scenario, where these features listed above are feasible, instruments defined as devices already mentioned in this text are unfortunately not suitable for this type of simulation. But for some years already there have been, not only tools' prototypes, devices that by characteristics, especially at hardware level, are suitable for this use: the Smart Glass (fig 7.1).

The smart glass is a wearable technological device that can add information to what the human eye can see and create virtual reality situations and / or augmented reality. Usually in these products, smart lenses, monoculars or eyeglasses are integrated into head mounted displays or computerized glasses with heads-up display (HUD) or mechanisms and interfaces capable of displaying additional information on what is seen or framed visually. The first smart eyewear models were limited to display and visual media for information sent by remote attendant wireless connections.

Fig 7.1 The Smart Glass in Augmented Maquette | copyright by the author

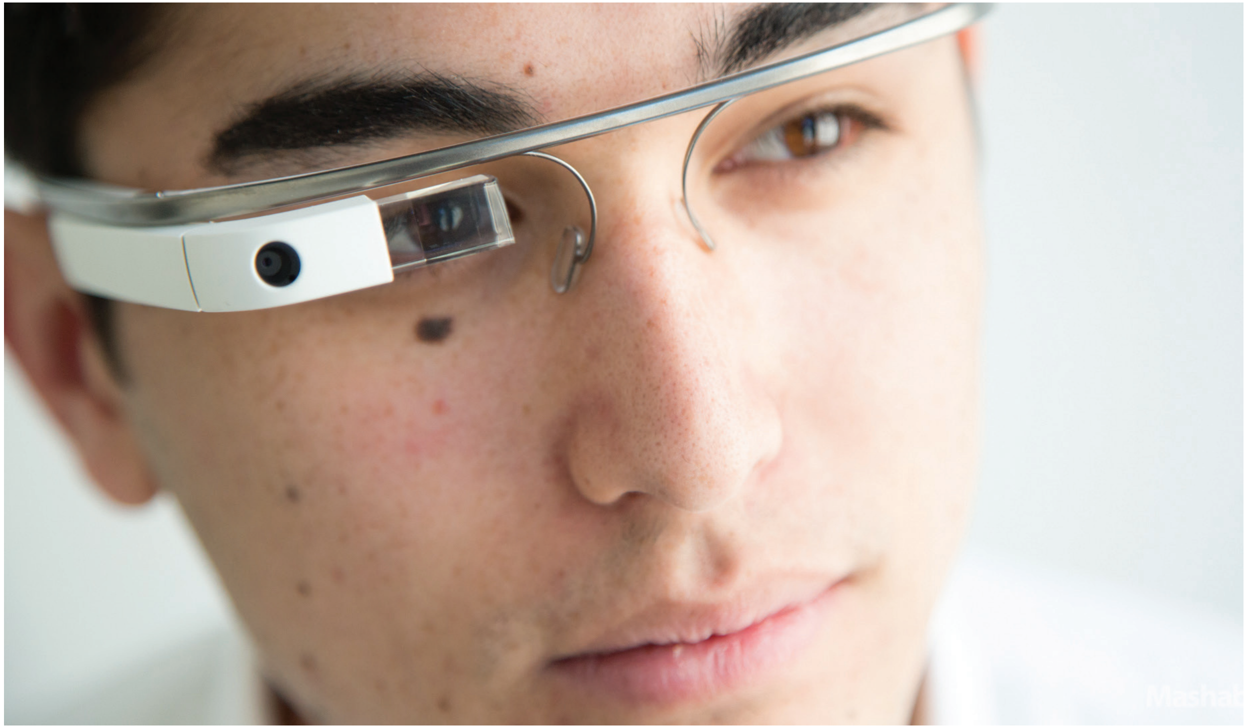


Today, new prototypes and products have become real-world intelligent, wearable, capable applications that feature voice interfaces that are always interconnected and interactive.
Many companies are working on the development of these devices; The author will then show some of the best known on the market in order to make the reader aware of what you are talking about exactly. It is not a comparative and qualitative analysis such as the one carried out on apps, but the desire to illustrate the type of tool that will be used in the future for this type of simulation and that it is already beginning to test.

GOOGLE GLASS

The most famous is the Google Glass, one of the first glasses device developed by Google Inc. trading in the first time in the United States at the beginning of 2013. Was the first attempt to market this kind of personal computing, but unfortunately the project was abandoned in January 2016.

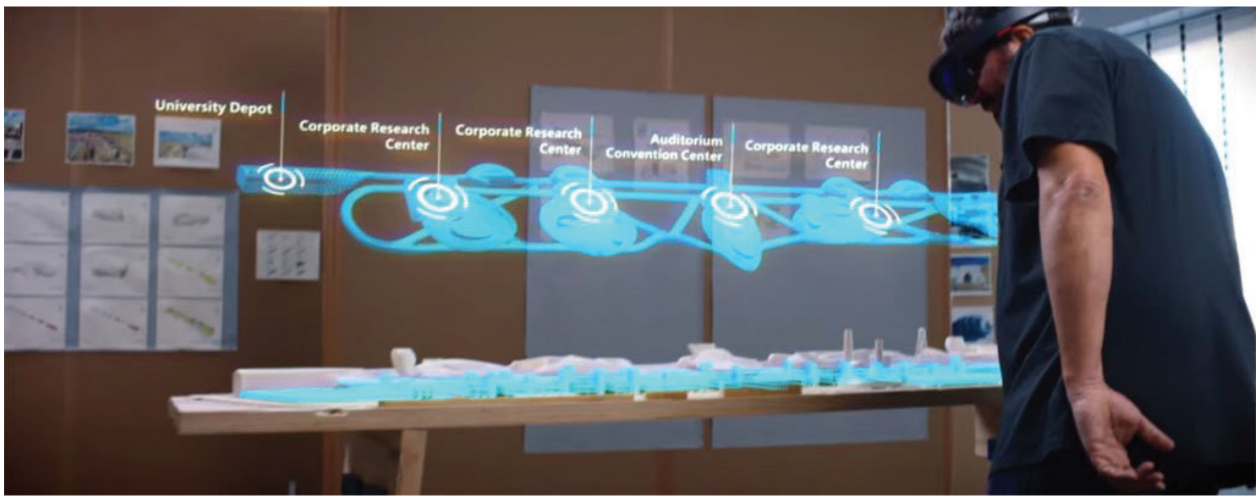
Google Glass Link: https://www.youtu-be.com/watch?v=wTxFxk2dwaQ



HOLOLENS

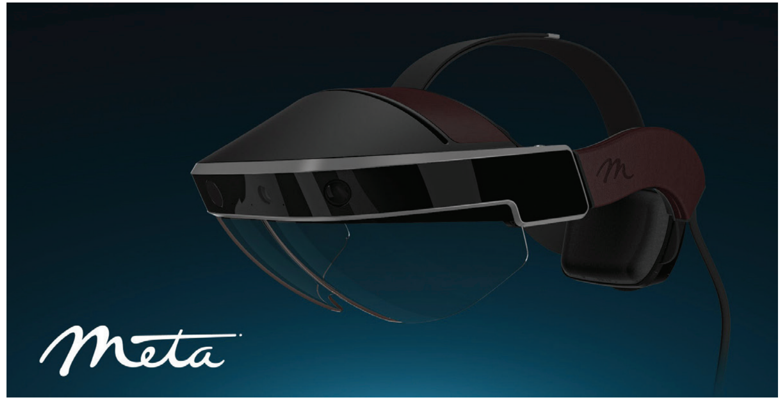
Hololens developed by Microsoft, made up of specialized components that together enable holographic computing. Much more effective than the above-mentioned google glass, because I do not just add date and time information, or let you take videos or take pictures, but create real holograms with which users can interact.

Fig 7.3 TOP: Hololens by Microsoft | image copyright Microsoft
BOTTOM “Microsoft HoloLens: Commercial Customers are Transfoming Their Businesses”
Link: https://www.youtube.com/watch?v=MbgL5XPFXAQ



META 2

By doing some research in the field of smart glass, as the last example, the author proposes a model developed in 2016 by Meta Vision company, born in 2013, the Meta 2 device (Fig 7.4), with a lesser known name than the two companies mentioned earlier, but probably, at present, the most efficient smartglass prototype in augmented reality field.



7.4 Meta 2 by MetaVision
https://www.youtube.com/watch?v=x6XcZOP-PKU

06

CONCLUSIONS AND FUTURE PERSPECTIVES

The core focus of the Thesis is research relates to an instrument that has always been considered indispensable for design, the physical model, in a more futuristic context. It is ideal for communicating with a non-expert public because the way you can interact with a maquette makes it a key point for the involvement; people can interact directly with it, and the perception of a real 3D object is totally different.

The *Augmented Reality* and its technology helps to implement new elements inside the model, and shows hidden information which are not visible inside the mockup. The in-depth knowledge of Digital and Scaled models investigated in **Part 1** was crucial to better understand the relationship between them in terms of classification of Level of Details.

The *first part of the text* presents, in fact, pros and cons of physical and digital models from different point of views, starting from a general overview and continuing to go into the merit of Level of Details. The investigation comprehend standardizations of LoD for digital model starting with their birth and following their evolution. This analysis has allowed us to understand and gain enough notions to make physical models suitable as much as possible for "augmentation"

The author has considered and analyzed many case studies, characterized by different nature, but in the process within them, they possessed relevant qualities at scientific and experimental level (e.g. the approach to a no-expert public involvement; application of new technologies for urban simulations; different Mixed Urban Design solutions; etc).

What emerged from the case studies gives precise indications and suggestions:

- The inclusion of citizens in the project in order to keep in mind the main goal, design thinking about who is dedicated to the project, to the needs of those who will live there; AM can represents a good support tool for co-design participations.
- Set the presentation of a project in an interactive and sometimes “playful” way could help to better involve participants and allows them to clearly understand the project; It also makes them feel part of the process, and then accumulate consensus or even take interesting ideas.
- This type of proposal, Mixed Reality urban design, has already been used by several research laboratories in the field of architecture and urban planning, also with a support of a mockup, both for research and didactics; it is very effective because it is possible to see modifications in real time (very useful during on going process). AM could represent a new kind of simulation of the effects of a new project.
- Although the physical model may in some cases be considered obsolete, it is still a widely used instrument; This is because it has features that Virtual Reality, renders or plants can not replicate with the same perceptual characteristics.

In **Part 2**, the author was finally able to illustrate the proposal, named Augmented Maquette. The study and research carried out and illustrated in the first part, that is the standardization of the level of details considered so far for digital models, allows the systematization of the ***CityGML standards***; consequently, is possible to define a new standardization for LoDs on the maquette , to make them as much as possible suitable for Augmentation: combining LoDs analysis and a feasibility study linked to scales of representation, the author has defined M LoD standards. In a nutshell, M LoD represent a ***new reference framework to optimize the integration of physical and digital models.***

Simultaneously, with the study of the new LoDs, a qualitative and comparative analysis has been achieved between several Augmented Reality Apps for smartphones and tablets, commonly used tools and accessible to anyone to study the effects of adaptation. In fact, there were many defects, mainly due to the fact that these apps were designed to be used for outdoor viewing and outdoor use;

using these apps improperly by adapting it to scales very small as those of physical models, highlighted some technical shortcomings. First of all, the aim of this analysis was to highlight which kind of results we can perform with technologies available to us today; secondly, highlights technical problems currently found, and therefore what it would need to implement to use apps with models for planning and urban design. Hence, technology development can design in the future such software to support the *Mixed Reality Urban Design* proposed by the author.

In addition to the analyzed apps, the author proposed some examples of new devices classified as HMD, Smart Glass, designed solely for the use of Augmented Reality; they would be the perfect tool to support the physical model, and therefore of the *Augmented Maquette.*

Basically, the digital era seems to simplify the work too much, such as the design choice of working totally on a digital model rather than on a physical one; but trying to keep something traditional, like in this case the maquette, is not something old or passed; it helps us not to totally detach ourselves from the real environment, and always allows us to touch real objects with which it is possible to interact and feel.

What emerged from case studies too, shows how this kind of mixed solution supports and helps in *evaluating design effects and co-design processes*, creating an instrument on which more people can work simultaneously and in real time; hence, is a powerful *communicative tool suitable for both a non-expert public and professionals in the public presentation phase* of the project.

FUTURE PERSPECTIVES

Augmented Maquette is still far from being a real effective urban simulation tool and within reach in the urban design domain. Despite these constraints, AM is still very promising, due to the fact that technical defects (hardware and software) can be easily solved by the continuous development of specific AR technologies.

The Thesis represents a *reference framework to set up a possible future solutions which is the combination of the "old" tool (maquette) and the "new" technology (AR).*
To further develop the research it would be useful to deepen the issue of the standards for the level of detail of interiors - separating it from its outer shell as it was also done for the CityGML standards in its latest versions (where the interiors have a separate classification); this topic has not been thoroughly investigated by the author because it is mainly based on the expertise of architects and designers, but still related to the augmented maquette proposal.

Also, it would be interesting to continue the analysis by carrying out more concrete tests through case studies applications ; see the effects on a real case, might raise different issues, and lead to a fine tuning of the methodology . Therefore, we started a process for testing the applications of AR in architectural higher education within the course of Architectural and Urban Simulation, proff. B. Piga and R. Salerno, at Polytechnic of Milan, and within a process of public participation related to the Campus Sostenibile project, in order to anticipate new urban simulations possible applications for urban design and planning.

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