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Virtual Twins of Architecture: The Singularity of the Profession and the Field

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Abstract

Architecture is facing a singularity; the focal point of the singularity is virtual reality, virtual twins of architecture, and virtual public space, a central principle is the (so far inaccessible) authentic diachronic perception of architecture and its instantaneous creation from spaces within space. Architecture should embrace the singularity and undergo a reinvention of the discipline and the profession to rid itself of accumulated problems that often escape attention and whose essence is hidden. The prospect is to transform the paradigm of architectural design and built environment development planning, understanding architectural designs and communication with them, about them, and between interested professionals and the public. The benefits are to be numerous qualitative and quantitative increases in the performance of the profession and widespread and diverse improvements in the conditions and societal and sustainability profile of the built environment and architecture as a discipline. Based on a review of the state of the art of the field of software for architectural and building design, the paper reports on the research and development of a new software tool and virtual reality environment—Wearrecho—which fulfills the intended transformation and becomes its platform that links the virtual reality environment and parametric BIM software. The prevailing positive results of the experimental validation of their performance are presented, followed by a plan for continued research and development.

Keywords: *Public space, Communication, Participation, Virtual reality, Architecture, Construction, Bulit Environment,Computer-aided design, Building information management, Poiésis, Parametrization, Creativity, Industrialization*

1. Introduction

Architecture, as a mode of human existence, is facing an exceptional point in its history that offers an unprecedented development of the discipline and the field. This singularity is represented by a technological phenomenon—the current research, development, and news in the field of computer technology, which is represented by the phenomenon of virtual reality, more narrowly the virtual twins of architecture and the built environment. The paper presents the results of research and development in this field: An experimental

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software complex for an instant design of architecture—authentic design of architecture in and from spaces in a virtual reality environment, which is a platform for not less instant communication of project stakeholders with each other, with the designers and with the objects themselves; the product of the work and communication is a consensual virtual twin of the future (or even physically existing—managed or ready to be modified) architecture, an entity of the built, hence synthetic environment, provided with a comprehensive set of information on parametric—physical, chemical, commercial,... properties of its structural and spatial parts and the whole. Finally, such a twin exists in parallel in the virtual reality environment and the parametric environment of the standard Building Information Management (BIM) software for construction planning—and in both these environments, it is possible to interact with it, process, to create it.

It would be a mistake, however, to reduce the singularity of interactive and communicative virtual environments and virtual twins to a technical phenomenon: essential is the unity, the inherent interconnectedness of new technical opportunities with a new way of thinking about architecture and approaching its design in the context of the sustainable development of the built environment and the sustainability of life on Earth in general. If progress is not to be exhausted in the refinement of craft skills, perhaps in the improvement of the socioeconomic conditions for the practice of the architectural profession, and perhaps even before the fulfilment of such a truncated potential, it is necessary to perceive and further study the starting points of the singularity and the diverse fields of its development potential and effective application. The annotated conception of architecture and the built, or synthetic environment respectively as a mode of human existence, based on the phenomenology of Husserl (*... phenomena do not appear, phenomena are experienced* (Husserl, 1976)) and Heidegger (*... poetically dwells man* (Heidegger, 2000)) and its elaboration by Norberg-Schulz (1985), emphasizes the general, social and existential relevance of the "disciplinary" singularity and the need to perceive it in a broad context. The existing awareness of these contexts is far from complete: this paper presents an indicative overview of the current knowledge of "Where we come from" (Gaugin and Malingue, 1949) and "Where we go", and shows that "What we are" is a virtual public space in which we can "live", interact with each other and (above all) directly interact with the virtual twins of architecture and the built environment in their various phases of birth, existence and demise or (better) transformation, and reuse.

State of Research and Development in the Field of Virtual Reality Tools for Architecture and Building Design

The consistent embedding of the presented research and development in the context of the tasks of sustainable development, the socioeconomic situation and perspectives of the architectural field, and the professions of architect and builder (or designer) as the primary, but certainly not the exclusive user of their results—the technology of direct and interactive communication and creation of architecture in parallel with parametric building design—BIM—distinguishes the presented project with the protected mark *Wearrecho* from the state of the field and shows it as unique and ahead of the curve. The following of a broad, "extra-professional" and "extra-disciplinary" context and the continuous updating of the starting points and development goals are the fundamental principles of the presented project and the basis for maintaining its uniqueness and paradigmatic and functional edge. The history and characteristics of "competing" software tools and the data on the numbers of their users (which are in the hundreds of thousands) show the excellent potential for further development and application of *Wearrecho*. Leaving *Wearrecho* aside, the benchmark for the state of the field is primarily these software tools:

Mindesk: Allows a transfer of modeling from Rhinoceros and Solidworks software into a virtual reality environment in the original Unreal Engine gaming tool. It is narrowly focused on industrial and product design. It does not allow full collaboration of multiple users on a single project; only the model is displayed in virtual reality, not textures and materials. It does not have bi-directional real-time connectivity to parametric environments. The company, formally founded in 2015 in Italy, has been developing the product since 2014 and providing it to other users on a commercial basis since 2016 (https://blog.vive.com/us/vive-x-company-mindesk-secures-900k-bring-cad-designers-virtual-reality).

The Wild: Enables the transfer of a model from Sketchup and Autodesk Revit to virtual reality. It is a multi-platform program that allows one to move components, change materials, sketch, and post notes in virtual reality. It does not interface with real-time parametric environments, allows multi-user collaboration, and is primarily focused on presentation (https://irisvr.com, https://thewild.com/about-us).

Arkio: Works with models created in Autodesk Revit, Sketchup, and Rhinoceros, but lacks several key functionalities: it does not have a direct bidirectional connection with Autodesk Revit or other parametric

software, the modeled elements cannot be controlled backward in the default environments (Revit, Sketchup, ...), it has worse drawing. It can model in virtual reality, allows multi-user collaboration, it is a multi-platform software. In 2017, an alpha version of Arkio was created, a beta version was launched in mid-2019 and two years later version 1.0. Software development is, probably for marketing and economic reasons, connected to the development of hardware—Oculus headsets (https://www.arkio.is/blog/2021-06-01-release-1dot0).

Spacemaker: It is a web application that models large-scale urban areas in the browser with their surroundings from publicly available data sources. The models are then analyzed by artificial intelligence, and the input data can be provided to the AI to generate its designs. The software provides area analyses, room daylight analyses, acoustic analyses, wind flow analyses, and more: it comprehensively evaluates the microclimate based on the results of the analyses. Spacemaker works with Autodesk Revit, but only in a "one-way" way—it does not allow editing of the BIM model, nor display in virtual reality. The development of Spacemaker began in 2016 in Norway (https://www.spacemakerai.com/).

The survey did not reveal any software that would have a two-way real-time virtual reality connection to the parametric BIM environment, no solution that would allow full editing of elements created in parametric software in the virtual reality environment. No parallel of the approach of the presented research and development, consisting of the user-friendly and, at the same time, authentic design of architectural space "in the first person", from the inside and in a one-to-one scale, was revealed. What remains unfulfilled is the perspective of virtual reality as functional open communication and public space, an environment of authentic spatial creativity, and, at the same time, a seamless two-way real-time information-no-loss communication with environments of parametric software established and proven for construction planning.

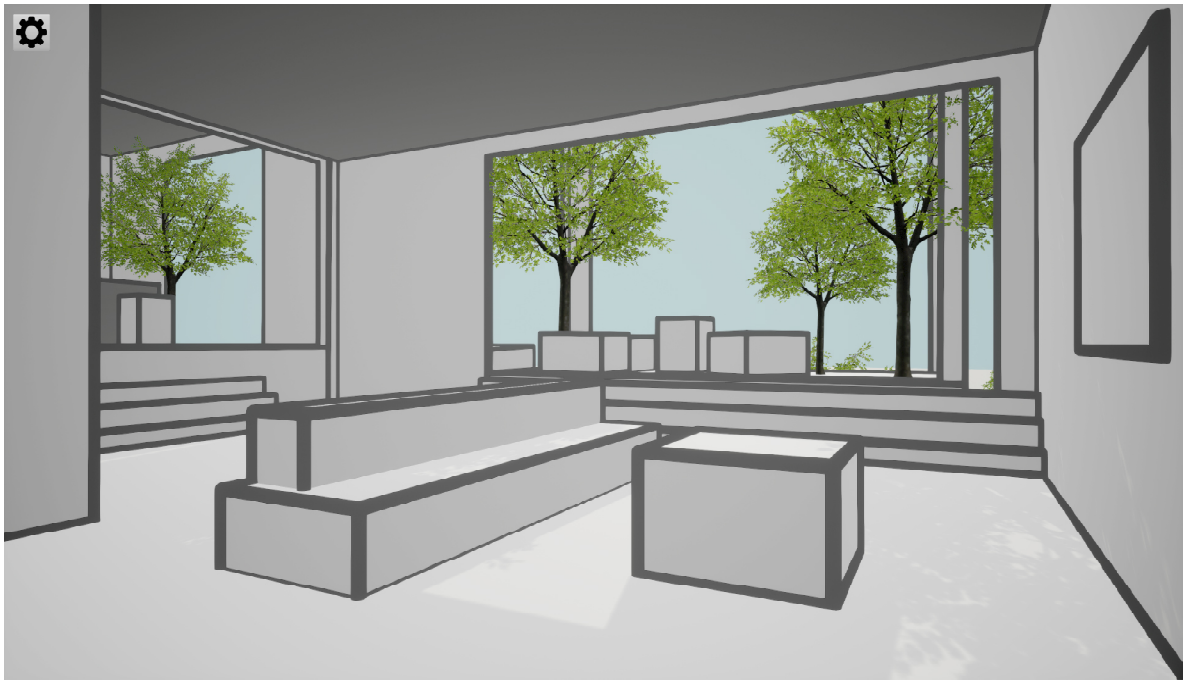

Figure 1: Space is the Basic Building Block of Architecture: Space, not Structure or Material. Student Work in Wearrecho, Image from the Author´s Archive

The State of the Field of Architecture and the Architectural Profession, to Which Research and Development are Responding

The situation is probably due to the history and the current state of views on architecture and the built environment and the approach to them by both designers and clients—of the whole society, in the most general sense: the presented R&D, even if the nature of its output is technological, must know and understand the situation if its ambition is to contribute to practice. If it turns out that the effective application and acceptance of its technological output is contingent on a paradigm shift in professional, disciplinary and societal terms, R&D must not overlook and must come to terms with the loss of architecture's relevance as a profession and a

discipline to public space—and the rediscovery of its appeal and relevance thanks to (among other things) the epidemiological constraints of 2020 and 2021. The project responds to the sidelining of the architectural profession not only in terms of the prestige of the profession, but above all in terms of the expectations of its benefits. The relegation of architecture from the position of *summum templum* (Vitruvius, 2005) is a consequence, above all, of the decline in the consideration of public space (Sourek, 2014), which was initiated in the 18th century by Laugier's *primitive hut concept* (Laugiere, 2012) and culminated—after the peripeteia of interwar architectural modernism (Giedon, 1967)—by the International Congress of Architecture (https://en.wikipedia.org/wiki/Congr%C3%A8s_Internationaux_d%27Architecture_Moderne) and the *International Style* (Johnson and Hitchcock, 2022) in the 1950s and 1960s. Architecture was further sidelined by the massive emergence of the virtual public space of multi-platform information and communication technologies from the late 20th century onwards: a person 'glued' to a mobile phone screen is of little interest to his physical surroundings—until the quarantine reminds him of their value, significance and attractiveness.

The (so far) last "nail in the coffin of architecture" is climate change. The built environment is an environment outside of which humans cannot and do not want to exist. For sure, man relates his existence to "nature", to the natural, unmodified environment, too, however man and human society can survive—physically and mentally—only in an environment that man has been modifying since the beginning of history and further modifies, builds, constructs for his existence. And this environment is today accused of being responsible for 40% of the emissions of externalities (https://worldgbc.org/news-media/commitment-includes-embodied-carbon#:~:text=The%20built%20envir onment%20is%20responsible%) that result, among other things, in climate change: the material world of human existence is supposed to be the cause of humanity's extinction (Gaugin and Malingue, 1949). The unspoken interpretation is that this is the fault of architects and builders, who are incapable of designing buildings and structures that do not threaten the sustainability of life on Earth. Thus, environmentalists and energy specialists are called in to help, deciding (among other things) how big and where a building's windows should be, how plastic its perimeter may be, ...: architects are deprived of their self-government—unless they declare their subordination to the energy and environmental specialists.

Concerning craft and communication, research and development respond to the contradiction of the inherent three-dimensional spatiality and the diachronic (Arnheim, 1966; Zevi, 1957) perception of architecture on the one hand and its only two-dimensional and static (to a decisive extent) representation on the other. The basic tool of an architect is his head and the poetics and imagination hidden in it. To show what he has created, to show it in a way that even a layman can understand, is not easy at all. What a layman: even a seasoned professional is sometimes surprised by the reality of what he has imagined and drawn. Since time immemorial, the main means of expression of an architect is the pencil or something like that. And the pencil in the hand of an architect draws only two-dimensional images, symbols of three—and multi-dimensional space—it does not draw the architectural space itself, but its schemes—floor plans, sections, isolated axonometric or perspective representations. Yes, since the 15th century we have had constructive perspective (Andersen, 2007; Cole, 2001; Hockney, 2001), since the turn of the millennium perspective representations are drawn by computers: one and the other, however, only based on those old familiar schemes—floor plans and sections. More or less the same applies to physical models of future architecture. In one or another of the established ways, the architecture present (so far only) in the design is presented to a synchronous perception that contradicts the actual perception, the experience of real architecture; moreover, only a slice, a fragment of it is presented in this way. The diachronic perception of architecture in design, architecture that has not yet been materialized, remains unavailable in today's good practice.

An overlooked, but all the more serious problem is the unclear relationship between the professions of architect and builder in the present. The basic building block of architecture is space, not structure or material. It is the space in which we live, which passes from the man-occupied landscape into the public space of towns and villages; it passes inside the buildings through the facades of the buildings that articulate the public space and give it meaning and form. By exposing itself in public space, the building becomes architecture: the space that architecture is about is above all public—whether directly or vicariously. This is the theory; the practice, however, is that architects usually regard themselves as builders in one way or another, and as builders, perhaps with an aesthetic sensibility, they are seen by virtually everyone else. It matters little that the Encyclopedia Britannica explicitly distinguishes between building and architecture: *architecture, the art and technique of designing and building, as distinguished from the skills associated with construction* (https://www.britannica.com/topic/architecture).

In essence, the relationship between construction and architecture is very similar to the liaison between agronomy and gastronomy. Raising Wagyu bulls is one craft, and making their meat an experience for our senses is another: interestingly, no one confuses the two. Very similarly—devising the space of a theater, a temple, or an 'ordinary' living room is one task, and proposing the structures that materialize such a space is another. The two tasks are closely related, indeed. Their solutions influence and inspire each other, but still, by their very nature, they are two different tasks. And they are distinct tasks even if solved by one head or team. The "dual profession" of architect and builder is a rule rather than an exception in practice and theory; the prevailing practice is to mix the two, to confuse spatial and structural issues—and their solutions with each other: the quality of solutions suffers then inevitably. Architecture is not an aestheticized construction; if its creator approaches it this way, he can achieve an optimal result only by chance.

The tools that either profession uses in its work exacerbate and preserve further the problem, which inevitably affects the quality of production. Digitalization is proving to be indispensable among the forces shaping the productivity and efficiency of material, and often ideas production in the 21st century (Aghion *et al.*, 2021). In terms of digitalization, the construction industry ranks last among industries; indeed, it is so far a typical "catch-up" industry (Vesely, 2004) that lags in innovation in general. And architecture is no better off within the built-environment development professions: the tools with which architects work today are "pre-flood" and unsuitable. Today, builders or construction planners most often work with computer programs such as Autodesk Revit, Archicad, Allplan: as a rule, parametric tools that focus on structures and that have been well developed for such purposes. Space, architectural space, is not addressed by these tools—space for them is what is left between structures. And yet they are successfully foisted on architects (starting at school, where architectural students may use them for free). What kind of result can a craftsman achieve who is dependent on a tool developed for another job, another craft? Certainly, architects have other computer modeling programs at their disposal—SketchUp, Lumion, Rhinoceros, ...: but they all work with volumes, not spaces, and render unable to overcome the principle of parameterization.

The usual drawing representations of architecture—from execution plans to photorealistic visualizations—compare to the instructions sold with bags of building blocks by LEGO. Experience shows that the average seven- or eight-year-old child will not build much according to this kind of instruction. But give a child universal "bricks" and a free hand—she will build a house easily and quickly. Space is the building "building block" of architecture: architects will create more easily and with better results once they have "building sets" whose "building blocks" are flexible, changeable, and easily "to be assembled" spaces: in virtual reality this is possible.

Exceptionally insightful architectural theorists perceived the manifestations of the unfortunate situation: far from the "business as usual" architectural practice, they had no chance to discover the causes. Nevertheless, identification and analysis of the problem are still useful when they identify a problem of which neither the profession itself nor its clients are aware. In his groundbreaking work Architecture in the Age of Divided Representation, The Question of Creativity in the Shadow of Production (Vesely, 2004), Dalibor Veselý critically revised Alberti (1988) on the threshold of the new millennium in a similar way that Alberti had critically revised Vitruvius (2005) five hundred years earlier from the position of the nascent modern period. The problem of creativity in the shadow of production is a manifestation and product of the mixing and confusion of the tasks of the architect and builder. The incongruity of the theme of architectural space on the one hand and building construction on the other is as fundamental as it is currently underestimated and overlooked. It is the incompatibility of the poietic principle (https://en.wikipedia.org/wiki/Poiesis) with the parametric, inherently mimetic approach.

The lack of understanding of the fundamental difference in the approach to designing both architectures on the one hand and construction structures on the other is almost general. Rather than architectural theorists, a section, however small, of professional practice intuitively identifies the negative role of parametric "construction" software tools in this respect: they derive from it a condemnation, hence a "blanket ban" on computer support for architectural design. Their error was foreseen as early as 1966 by Martin Heidegger when, in an iconic interview for Spiegel magazine, he glossed over our inability to grasp by thinking the foundations of a yet-to-be-born technical age (Augstein *et al.*, 1976). The problem is not Revit or Archicad—the problem is our/architects' inability to perceive what these tools fit and what they do not and to treat them accordingly.

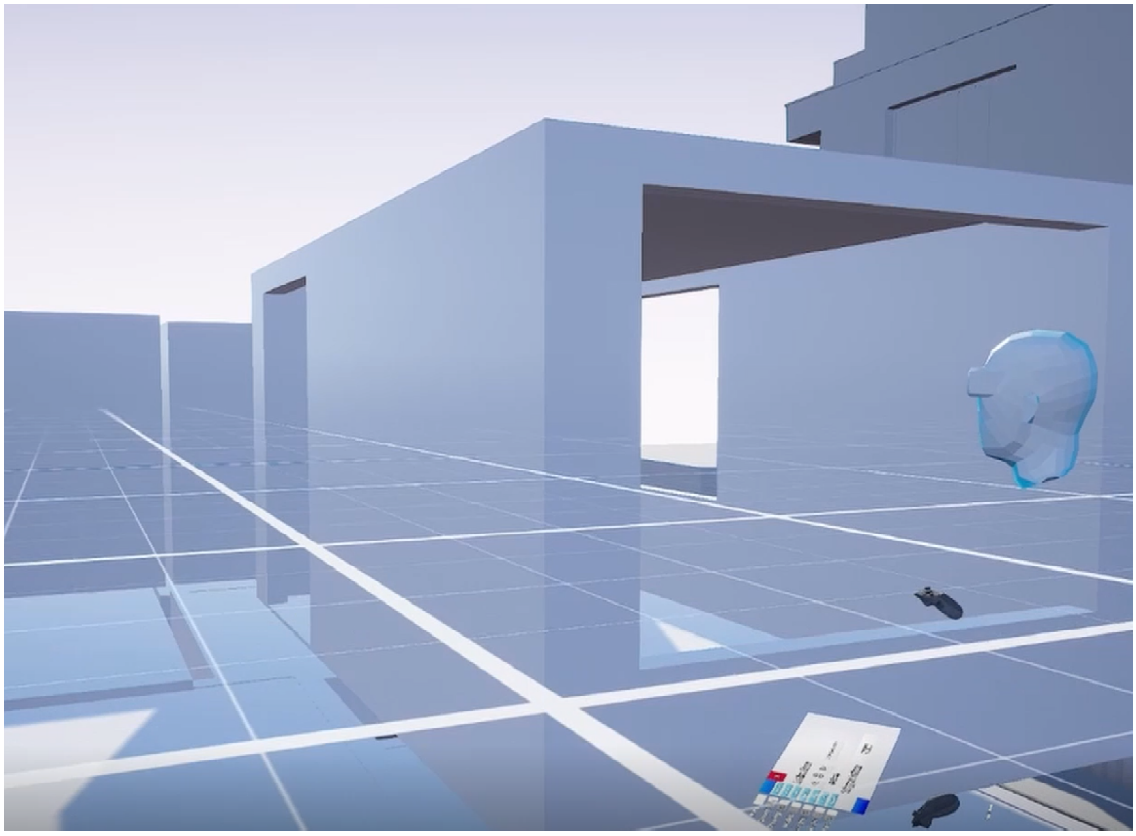

Figure 2: A Tool that will Consider Primarily the Space Itself, not the Structures Between which the Space will Hopefully Remain, is Expected to Promote the Creative Abilities of Architects and the Quality of Architectural Designs, Contribute to the Quality of Built Environment Development, and Ultimately Promote the Sustainability of Development in General. Screenshot of Student Work in Progress in Wearrecho, Author's Archive

How is the Paper Organized

From the craft´s view the point of the singularity under discussion is a pair of unprecedented possibilities: on the one hand, authentic architectural creation, consisting in working directly with spaces and in space—"in the first person", from the inside and in "life-size"—on the other hand, perception of architecture corresponding to reality (and human habit) from any place and diachronically—in movement through space according to the choice of the "viewer – visitor – observer" as well as the creator, in time and in changing light, possibly operational and atmospheric situations. (The functionalities of communication and interdependence with parametric software are derivative given these unique possibilities, creating together a specific open environment and a comprehensive functional complex). The technological goal of the presented research and development is the transfer of communication and interaction in the process of architecture design and planning of construction (and also its management in different phases of its existence) to the dual environment of virtual reality in parallel with parametric software for the design of constructions and management of buildings; communication in the virtual reality environment can be completely open and inclusive: the limit is the access to the Internet; the object of communication and interaction is the virtual twin of architecture, hence of the building—a future one or physically existing—its natural environment is the metaverse. The virtual twin can be a comprehensive representation of architecture and its construction substance in the design phase, within the search for solutions as well as an exhaustive basis for the management of buildings, modeling their various operational states and situations of use or preparing modifications of the material substance. The second part of the paper summarizes the assumptions of the development presented and the methods of its fulfilment.

In addition to the continuous building of user experience and the application of feedback by the development team, the results of the research and development were experimentally verified in the work of selected students of the Bachelor's degree in architecture and civil engineering at the Faculty of Civil Engineering of the Czech Technical University in Prague, who prepared their final theses—designs of a family house—in the virtual reality environment using the currently available version of the developed software in the summer semester of the academic year 2021/2022. The third part of the paper introduces the developed software, informs about the course of the experiment, and presents its results and a preliminary plan for further research and development.

The fourth part of the paper presents for discussion other possible areas of development, research, and development of the broad context of the virtual reality space and the phenomenon of virtual twins of architecture and built environment entities, the core of which is the presented research and development of a software tool and a complex software environment: communicative aspects and roles of virtual space, its competences, and performance as a public space and a space of extended human existence, which will be inhabited by artificial intelligence; the theory of architecture; economic conditions of technological development of architecture and built environment creation; issues of industrialization of the architectural profession.

Figure 3: Why not Bring the Complex Architectural Design Process as a Whole into Virtual Reality?! Technically, this is Already Becoming Possible, but is there a reason for us to want to do it? The Students at Work in Wearrecho. Author's Archive

The conclusion of the thesis recalls the context of the existing and achievable results of research and development—the outputs of the project—and highlights the benefits and importance of their achievement and implementation in professional, professional, and social practice. It outlines both the plan for further research and development of the functional realms of the *Wearrecho* tool and environment and the prospect of extending them beyond the topic of architecture and built environment development—the potential for applying the principles of virtual twin technology and interactive, open and inclusive communication in other professional and socioeconomic areas.

2. Assumptions and Methods

Today, architects can have a tool that allows them to create architecture directly—from and in space, in real size, and "in the first person". Similarly, architects' clients, project stakeholders, and the general public can

have the opportunity to perceive—and vice versa architects can have the opportunity to represent architecture in design in a way that corresponds to material reality—in three-dimensional space, in actual size, in movement through space and time, in changing microclimates and operational situations, diachronically, all together in mutual communication, in a shared realm, even regardless of where they are physically located. The medium that enables such creation, perception, representation, and communication is virtual (or augmented) reality. The representative of the proposed, hitherto immaterialized architecture in the space of virtual reality is its virtual twin.

The Virtual Twin

The virtual twin of a building, an entity of the built, hence synthetic environment, is its computer spatial model, which a person, equipped with the appropriate technical equipment, can perceive sensually from any position and diachronically—in motion, whose parameters correspond to what the person is used to, and (depending on the interest) possibly in its entirety—in contrast to the only synchronic and inevitably fragmentary representations available so far. The virtual twin is equipped with attributes that generate sensory perceptions close to those of the physical twin—the physical twin—whether existing or not (yet). The virtual twin can convey more than sensory perception, an experience of architecture that is closer to the real one: it can represent also the (future, planned) material aspect of the building that is to materialize the architecture. At the same time, the virtual twin can be equipped with a compressive set of extra-sensory information—data characterizing the physical and chemical properties of the physical object, a set that allows to observe its behavior in all respects monitored by available computational techniques—and to simulate the corresponding behavior of the virtual twin.

The virtual twin can then exist both in a virtual reality environment and in the environment of a parametric software tool for construction planning—typically Autodesk Revit, Archicad, Allplan, ... —and in each of these environments the architect and / or planner can work using the functionalities of that environment and in the ways appropriate to it. It is suggested to refer to such a virtual twin as a dual twin when it exists in two environments in parallel—when it seems to be two twins. But this would be misleading and undermine the benefits of the new technology, or more accurately, it would be a negation of the technology itself: the twin must

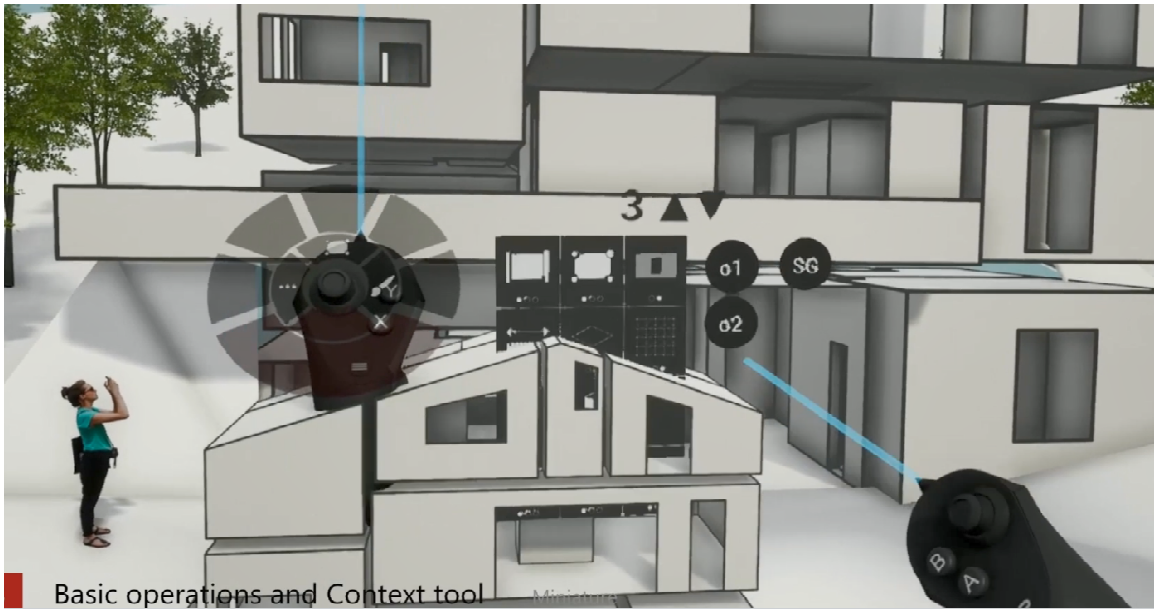

Figure 4: From Spaces, Created Intuitively from the Inside According to their Poietic Nature and Purpose in a Logical Sequence from the Decisive to the Complementary and Service Ones, the Students Creatively Build in Virtual Reality a Structure of Authentic Complex Architecture. Screenshot of the Student Work Process in Wearrecho, Author's Archive

remain one, only in each of the two environments different of its attributes are applied, including “accessibility” for different functionalities. A pair of twins would be a step backward not only because they would already be triplets: modifications made to the virtual twin in one environment must be preserved in the other environment, too, regardless of whether they are identifiable and active in the conditions of the other environment or whether they are hidden and passive. In other words, it shall be the creator or the observer who moves from environment to environment, the members of the creative team can be present and can access the twin in either environment, but the twin is still one and evolves as one. The existence of two twins—representatives specific to either the virtual reality environment or the parametric construction design tool environment—should be rejected as it implies the need to transfer changes made to one of the twins to the other twin—and transfer implies errors, even if automated.

Defined thus, the twin represents an ideal attainable yet only partially, imperfectly. Also, the possibilities of instant creation and modification of virtual twins have been limited to object-based interactivity in the current praxis, limited by an assortment of predefined libraries. But this is not designing—it is the old, clumsy process of trial and error, of intuitive designing blindly—of verifying the design—of optimizing it, again blindly—and so many times over, until the “right” thing is hit blindly—or until the author gets so tired that he is satisfied with a suboptimal result.

Released Creativity and Building Information Management

This paper reports on the development of an unconstrained instantaneous spatial and material creation technology in virtual reality and the positive results of experimental verification of the development results. Even the imperfect versions of virtual twins available today or in the near future can be the starting point for major innovations—including a paradigm shift in good practice for architectural design, construction planning, built environment development planning, their preparation, and the involvement of builders, investors, administrative institutions, public participation, and the collaboration of others. Architects will and should seize the opportunity to take responsibility for their creativity and imagination, which will no longer be constrained by imperfect tools and tools that are inappropriate because they were developed in a bygone era, that did not have today’s technological capabilities, or that were developed for a different purpose. The (virtual twin) space articulated in space “in the first person”, intuitively, in motion, and in “life-size” in their work will replace the hitherto only two-dimensional, static, fragmented synchronous representatives of the proposed architecture: if architects start working with it spontaneously and easily, so much the better—the responsibility rests on them. They must accept that in virtual reality it is possible to design architecture instantaneously—without the usual trial and error process. For the layman—from owners and investors to the participating public—the task seems easier: the architecture of the virtual twin in the space of virtual reality will offer itself to their perceiving, becoming more and more similar to the perception and experience of the real, materialized architecture itself. The decisive progress and change emerge with a data set at the level of cutting-edge current Building Information Management practice and data sets for quantitative evaluation of parameters in the categories required to be followed by statutory regulation and good project development practice. On the sensory side, there is a similar potential for visual, and soon acoustic and tactile, sensations that simulate reality well. The possibility of simulating free “natural” movement in virtual space, which in an unprecedented way evokes a diachronic perception of architecture and the built environment that is natural to the “viewer” and which no current architectural representation technique has provided so far, is proving to be essential.

Communication and a Metaverse Perspective

The third decisive characteristic of the virtual space—the environment of virtual twins—is its openness, inclusiveness, communicativeness, ability to share, and full interactivity: no one (who is equipped with the appropriate technical equipment) is denied access, all “visitors” can meet in it, communicate with each other, use the tools of presentation and instant creation of virtual twins, and watch their transformations and behavior in the process of creation and the changing conditions in the virtual space.

Since the middle of the second decade of the 21st century, the public space of information and communication technologies (Sourek, 2014) has been gradually adopting elements of the metaverse (https://academy.binance.com/en/articles/what-is-the-metaverse?utm_campaign=googleadsxacademy&%20utm_source=bing_ads&utm_mdium=cpc&ref=TDJYLZ1Y&gclid=3b820716896c10a0aace6417b6423bf8&gclsrc=3p.ds&msclkid=3b82071689 6c10a0aace6417b6423bf8); step by step, virtual public space is inhabiting

the space of virtual reality. In October 2021, Meta was formally announced—a new brand and project of the Facebook concern and a new social network by which the four billion community of existing Facebook users will gain access to the global virtual public space. Meta is the most robust, but certainly not the only "usher" into the public space of virtual reality—and more will undoubtedly follow. The number of physical visitors, hence users of the public virtual reality space is limited by access to the Internet (66 % of the world's population and 90% of the population of Europe and North America in 2022 (https://www.procomputing.cz/v-evrope-a-usa-se-mira-rozsireni-internetu-mezi-obyvateli-pohybuje-kolem -90/)), and by the hardware, or rather its alternative available to the average user, in whose technical development and affordability Meta, among others, is currently investing massively. By a realistic estimation, the "inhabitant" of the public space of Meta-version may be one in three inhabitants of the Earth during the third decade of the 21st century, and by the end of the next decade at the latest, the penetration of the public space of the metaverse may equal today's value of the share of mobile telephone users—86% of the world population (https://www.patria.cz/zpravodajstvi/2169166/pocet-uzivatelu-mobilnich-telefonu-na-svete-stale-roste-a-n a-konci-lonskeho-roku-jich-bylo-jiz-zhruba-sest-miliard-tj-mobil-vlastnilo-86-lidi-ze-100.html). Placing the virtual twins of the yet-unimplemented architecture, the yet-unimplemented development of the built environment into the global space of virtual reality—connecting the virtual space of individual projects to the global metaverse is a technical detail that is unlikely to remain unresolved. For the active participants in the projects—those who drive them—and for those who "just want to be there"—from architects, designers, builders, and investors to public administrations and the interested and "surfing" public, this will mean a breakthrough in facilitating access and communication: if until now the paradigm shift of the whole sector could be considered an ideological proclamation and a "castle of air", now, it is proving to be real and desirable.

Professional and Theoretical Framework

The presented developed tool for immediate architectural creation and (at the same time) construction planning, and communication, a tool for the immediate design of (virtual) spaces in (virtual) space—a tool with the protected label *Wearrecho* for the creation of virtual twins, located simultaneously in the virtual reality environment and in the parametric BIM environment, has the ambition to become the pivot of these far-reaching changes that will positively influence the paradigm of the profession, the industry and, through the built environment, the entire society. The transfer of architecture in its processes of birth and of the discussions on it to virtual reality is not only a technological innovation: it is also an effective intervention concerning the problems of architecture, whose denominator is public space. Virtual reality is one of the platforms of the public space of information and communication technologies, in which people are now primarily "at home": public space is thus returning through a "window" to the field of view of the public from which it has been pushed out through a "door". The virtual public space, which has collaborated in relegating architecture to the sidelines, joins the epidemic restrictions of the covid epidemic of 2020 and 2021 and reminds us of the attractiveness, even indispensability, of physical public space—even if (for now) only represented in virtual reality.

A virtual twin of the future building, equipped with comprehensive information on its physical and chemical properties, which allows to monitor its behavior in all respects available to computational algorithms—and to simulate its corresponding behavior and the variation of dependent parameters, will allow the designer of the architecture and the development of the built environment—among others—to confront in the public space of virtual reality the schematic thinking and simplistic "standards" of energetic specialists and environmental activists: this will allow him to regain the role and authority of a sovereign, albeit listening principal of the design process.

Though only assumed, the duality of the virtual twin solves the problem of the "double role"—the duality of the profession of the architect and builder. The architect—builder encounters the tasks of one or the other profession exclusively in "its environment": the issues of poietic architectural creativity in the open environment of virtual reality, the problems of constructing the building that is to materialize architecture only in the parametric environment of software for planning constructions. Then, he can hardly fail to realize "who he is" —what is the nature of the question of the design of architecture or the planning of a construction he is facing. *The problem of creativity in the shadow of production* (Vesely, 2004) becomes solvable *as the basics of the yet-to-be-born technical* [or technological] *age have been grasped* [within the field] *by thinking* (Augstein *et al.*, 1976).

Benefits Expected

Unleashing the imagination of architects and supporting and enhancing their creativity with the technology of virtual twins and the adoption of a new creative paradigm will not only promote the quality of architectural designs. We can expect multifaceted effects in various areas of the profession, the field, the built or synthetic living environment, and the cultural and social sphere. We can foresee the following:

- Enhancing the quality and increasing the value of the proposed architecture and buildings;
- We can expect improvement both in the context of the comprehensively conceived quality of the architectural work and in the quality of the materialization of architecture—its structural and technical solution;
- Renewal of an authentic understanding of—and designing—architecture in the context of public space,
- Among others, within the framework of fundamentally improved communication, especially concerning public space, a more fundamental involvement of the public in the processes of formal and informal participation within the preparation of projects can appear; the fears that the project drivers—especially developers and architects—may feel in this context, the assumed, but also by practice verified positive effects of the presented technology in the field of perception and understanding of architecture and buildings will dispel: laymen—in short—will appreciate the "immersion" in the virtual reality of the proposed project: for the first time, laymen will lose their mistrust in communication with the architect and developer, they will gain (beyond the justified) feeling that they have comprehensively known the design and that they understand it;
- Making unbiased the choice of future architectural solutions and built environment development in architectural and commercial competitions (more in this respect in the fourth part of the paper) making the choice of future architectural solutions and built environment development in architectural and commercial competitions unbiased (more in this respect in the fourth part of the paper);
- Making unbiased and productive the search for sustainable parameters of development and transformation of the built (and synthetic living) environment; including the articulation of "sustainable architecture" and architecture and construction(s) solutions that contribute to finding sustainable responses to climate change; ultimately promoting the sustainability of life on Earth through architectural (including urban design) means and construction;
- Enhancement of the quality of life as an effect of improving the quality and increasing the value of public space and architecture; the revival of the perception of architecture as a fundamental factor of human existence and the development of human society.

The essential benefits of the proposed technology can emerge in various aspects and realms of communication. Public participation in the preparation of architectural and built environment development and transformation projects has already been mentioned. With improvements in this area, architecture and construction development will once again become a 'public matter' and a subject of positive interest to society. Equally beneficial is the improvement of communication between participants and stakeholders in the process of design and acceptance of architecture by society; this applies to developers and investors, professional specialists and industry consultants, public authorities, and the public. An important group that is also affected by improved communication is the providers of materials and inputs to the work of designers—from surveyors and providers of Geographical Information System (GIS) input through acoustic, traffic, environmental, and many other consultants to involved sociologists and demographers. In addition, the improvement of "internal communication"—both understanding and facilitated cognition of the proposals in the process by the authors themselves—is not negligible, too.

The benefits of the presented virtual reality technology will be not only qualitative and experiential but also quantitative and economic: starting with the increase in productivity of architectural design and planning of constructions, through the reduction of the cost of building structures and the development and transformation of the built environment, through the macro- but also micro-economically monetizable contributions of increasing the quality of public space, improving the sustainability attributes of constructions and the built environment and mitigating climate change, to increasing the market value of individual objects of the built, hence synthetic environment.

The list cannot be exhaustive: research and development are ongoing and may lead to further assumptions and findings. Indeed, the fourth and fifth sections of this paper provide further assumptions about the possible

(co)action and mediated contexts of the technology presented, especially in the socio-economic sphere.

Many of these assumptions can only be verified through experimentation or "in vivo" observation of practical architecture, the built environment, general and special sustainability, and society as a whole. The introduction of the presented technology into architectural design practice, which is a prerequisite of such an experiment or observation, does not imply any risk for the "recipient"— there is no need to fear it. Architectural practices operate in a highly competitive environment—technology that would lag behind others in any "front-end" respect, the "invisible hand of the market" eliminates soon.

The third part of the paper reports on the experimental application of the technology in the teaching of architecture and civil engineering students at the Faculty of Civil Engineering of the Czech Technical University in Prague.

3. Results

The transformation of the paradigm of architectural creativity and thinking about architecture, together with a unique new tool of spatial creation, will influence the next generation of architects and set new, fundamentally higher standards of architectural creation and its processes. Architecture students are the natural first line of deployment for a new tool for immediate architectural design in virtual reality. Unencumbered or less encumbered by traditionally skewed views of architecture as a discipline of volumes, facades, and construction, students can more easily perceive and tackle architecture as a spatial phenomenon. The natural playfulness builds on the still (almost) fresh universal experience of LEGO building blocks: from spaces, created intuitively from within according to their poetic nature and purpose in a logical sequence from decisive to complementary and services in virtual reality, students creatively build the structure of authentic complex architecture and continuously confront the gradually achieved result with a conceptual idea that does not remain rigid but dynamically develops. The results are convincing and the processes efficient and productive: these and the latter also provide valuable feedback for further development of the technology.

Application of *Wearrecho* in studio lessons at the Faculty of Civil Engineering, CTU in Prague

The presented technology for architectural design and construction planning in virtual reality was—for the first time in Europe, probably worldwide—applied in the summer semester of the academic year 2021 / 2022 in the teaching at the Department of Architecture of the Faculty of Civil Engineering of the Czech Technical University in Prague, Czech Republic. The students, who expressed their interest in participating in the experiment based on preliminary information, attended an introductory seminar to learn about the *Wearrecho* project, its current status, and the research and development outputs to date and their perspectives. Based on the information received, they decided to participate in the experiment.

The five-member group of Architecture and Civil Engineering students received the first working version of the experimental software for direct design of architecture in virtual reality, hardware—AMD Ryzen 7 5800X 3.8 GHz / 4.7 GHz workstation with a powerful gaming card, Oculus Quest 2 VR glasses. The students passed training on the authentic architecture design paradigm and an initial briefing for working with the *Wearrecho* tool. The software was—and the same is the premise of the final solution—hosted on the cloud, individual users have access via a link and unique code to their own space in which they set up individual projects; a good internet connection is important. The working version of the software possessed the following functionalities::

- Full immersivity in virtual reality space,
- Movement in virtual reality space by teleportation and free physical movement in the action radius of the headset connection cable (about 2 meters around the workstation),
- Intuitively accessible work operations: control with wireless joysticks in one and the other hand, switching functions with the joystick alone or in cooperation with the virtual floating tablet;
- The basic function is to create a real-size space around the user by moving the hands holding the joysticks; by default, it is the space of a prism;
- A free pen drawing in space can also create spaces and volumes;

- Other functions are the creation of any volumes using lines, curves, planar and curvilinear surfaces, basic geometric shapes, as well as a full range of spatial transformations, copying objects, cutting and copying holes, generating derived spaces ("next room"), of course deleting;
- All created objects can be edited by grabbing and dragging in free mode, in the global orthographic system, and in a local "ortho";
- Orientation in space is facilitated by giving the surfaces defining the spaces a particular degree of transparency, and the preview and the interactive miniature of the created structure;
- Import and inserting objects from other environments and formats (important for creating the "existing state" before designing—terrain and surroundings).

The working version had not yet developed materiality—students worked with spaces defined by abstract surfaces, with only schematic color and graded transparency available for resolution. Thus equipped, the students worked on the final thesis of the Bachelor studies of Architecture and Civil Engineering—a curricular design and project of a house. The interim results were positive beyond expectations:

- The level of task development was slightly more advanced after about 40% of the 13 weeks than in the comparison group of students who worked in the traditional way using the usual tools; it should be taken into account that at the beginning of the work the students of the experimental group spent about 15% of the period familiarizing themselves with the experimental approach, tools, and equipment;
- The creative level of the architectural concepts of the students of the experimental group was distinctively higher in general than the concepts of the comparison group; the spatial aspect of the concepts—the core and starting point of authentic architecture—deserves appreciation;
- In the consultations, the students involved in the experiment generally showed a very good level of understanding of the spatial-communicative nature of architecture and authentic architectural creativity—a distinctively higher level than the students in the comparison group;
- The preliminary fears that the technology involved in the creative process reduces creativity to productive constructing, to a repetitively mimetic and / or parametrizing activity, have not been fulfilled; on the contrary, it has confirmed that virtual reality is a space that supports authentic architectural creativity, the creation of architecture in ways and processes that—finally!—correspond to the nature and essence of architecture.

In the more advanced stages of the work, the students solved the lack of materiality, which the working version of *Wearrecho* did not yet provide, by converting the structure created in *Wearrecho* into a common software—SketchUp or Archicad—in which they refined the design in terms of surface structures, details of

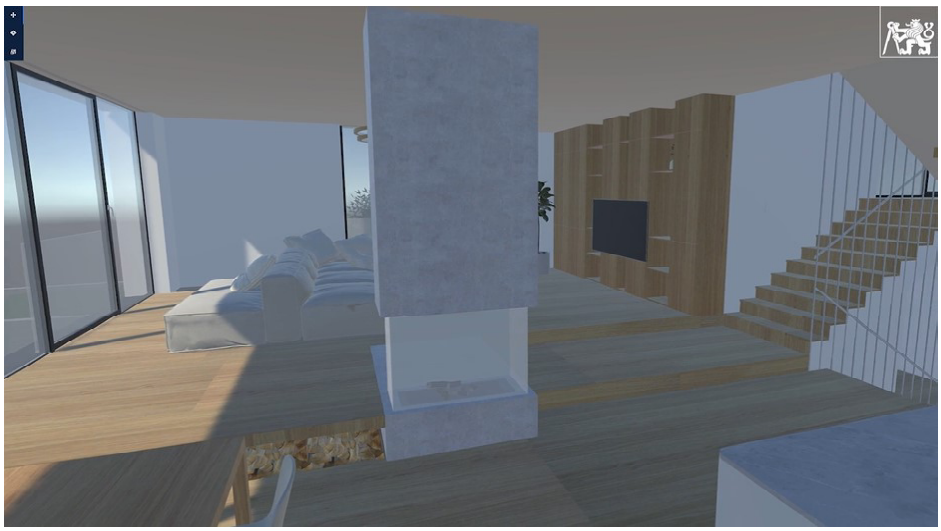

Figure 5: Virtual Reality is a Space that Supports Authentic Architectural Creativity, the Creation of Architecture in ways and Processes that Correspond to the Nature and Essence of Architecture. Student Work in Wearrecho, Image from Author's Archive

building elements (e.g. window frames) and coloring. As far as the "duality" of the virtual twin is concerned, the students had a connection between the virtual reality platform—Unreal Engine 4.0—and Autodesk Revit only at the level of polygons: therefore, the transfer of the created models to the parametric environment of the software for the processing of the plans of the construction design was done by a one-time export—due to the equipment and the knowledge of the students from previous studies to the Archicad environment..

Even then, however, the students tested and refined their designs in the virtual reality environment: with the support of teachers, university technicians, and Virtuplex virtual reality studio experts ((https://www.virtuplex.cz), they repeatedly converted their SketchUp and / or Archicad models into virtual twins that they could walk through and study in the Virtuplex studio conditions. The Virtuplex studio is a partner of the Faculty of Civil Engineering of the Czech Technical University in Prague, and its implementation conditions are European, probably even world-leading: the possibility of physical movement around a 600 m^2 area with headsets, connected to a computer in a WiFi network, in a group of up to six "visitors"—five students and a teacher—in mutual visual and acoustic communication. The students greatly appreciated such conditions, explicitly stating a further higher level of perception of architecture (confirming the fundamental importance of diachrony), its understanding, and the ability to articulate it. The unprecedentedly high intensity of communication—consultations between students and each other—was also a benefit in terms of the educational process. However, it is questionable whether this was a benefit of immersion in virtual reality or a transient effect of the new environment.

The institutional, "tangible" result of the experiment is five successfully defended bachelor theses without exception. The students generally achieved better results than they had achieved in their previous studies—without the support of immersion and virtual reality work. Based on the teaching experience, it can be stated that some of them for the first time—in the eighth semester of their studies!—understood the spatial and poetic nature of architecture. If their bachelor's thesis did not receive a superlative evaluation, it must be attributed to the fact that it is one thing to understand a phenomenon, and another to learn how to use it (however much virtual reality helped them in this regard)..

The preliminary plan for further research and development is:

- Evaluation of the results of the work of the first experimental group of students both in the expert council of the Department of Architecture of the Faculty of Civil Engineering of the CTU in Prague and the development team by September 2022;
- Release of the next, more advanced working version of the *Wearrecho* software in September 2022; a key component of this phase of development is the addition of materiality and the linking of virtual reality and the parametric environment of traditional "computer-aided design": the linking of the two environments is a prerequisite for the application of appropriate tools for both poietic architectural creativity and parametric structural optimization in the individual phases of the design of the architecture and its structural implementation;
- Completion of primary development and release of "clean" version 1.0 in the first quarter of 2023;
- Application of the *Wearrecho* software and the corresponding architectural design paradigm in other curricular projects in the studies of architecture and civil engineering at the Faculty of Civil Engineering of the CTU in Prague; three experiential groups of students are foreseen for the winter semester of the academic year 2022 / 2023;
- After appropriate evaluation and implementation of experience and feedback, systematic curricular application of *Wearrecho* 1.0 in the teaching of Architecture and Civil Engineering at the Faculty of Civil Engineering of the Czech Technical University in Prague;
- Involvement of other academic departments in the ongoing development of Wearrecho and its curricular application from 2023: other departments of the Faculty of Civil Engineering of the CTU in Prague and other faculties and universities.

Results of Further Experiments

The author of the paper applies development versions of Wearrecho software and virtual reality technology in his architectural practice. The dissertable output of these experiments is, among other experiences, clients' reactions to the presentation of architectural designs in an immersive virtual reality environment. The results

of two experiments in this respect are available: firstly, the case of the design of a new cemetery for a small town in the Central Bohemian Region, and secondly, the case of the design of the incorporation of a client center and offices into the existing production hall of a leading global toy manufacturer; this project is also to be implemented in the Central Bohemian Region. The relatively small number of experiments is due to the financial demands of presenting designs in the immersive virtual reality environment rather than the short time the technology is available. The highest level of immersion and diachrony, the closest approximation to physical reality, is provided by the conditions of the Virtuplex studio. For them, the "normal", working virtual reality offered by any working software—Wearrecho not excluded yet- is subject to data optimization and / or format adaptation. The latter is rather time and capacity-consuming, and therefore costly; and renting studio space and technology equipment is quite expensive, too. Both experiments confirm that the "additional" costs borne by the client in this context are more than outweighed by the added value of the client's understanding of the design, and his grasp of the architecture: but this is only evident when the client has completed the immersive tour.

Figure 6: The Creative Level of the Students´ Architectural Concepts Provided with the Aid of the New Tool is Generally Decisively Higher; the Spatial Aspect of the Concepts Deserves to be Appreciated. Student Work in Wearrecho, Image from the Author's Archive

For both cases, it can be stated that the layman—the client without any previous preparation not only immediately understands the proposed architecture and gets the (quite justified) impression that he knows it in its entirety and understands it in its details, but—surprisingly—"accepts it as his own". Understanding and knowledge of architecture have a very positive effect on the efficiency and speed of communication and discussion between the designer and the client. In both cases, the personal involvement of the top representatives of the corporate or institutional client, which is not common in these processes, contributed "additionally" to this: however, it cannot be ruled out that this is just a novelty effect, which will eventually—as virtual reality becomes established in the processes of preparing architectural and construction projects and "domesticates" (strictly speaking—vice-versa—as the processes of preparing projects "settle" in the virtual reality environment) —fade away.

The cemetery project benefits from the communication support of the virtual reality environment also in the process of communication between the architect and the designers of individual parts of the future structure and in their spatial coordination (the second experimental project has not yet reached this stage). The designers universally welcome the possibility of clarifying the details of the task and the mutual spatial coordination in the "real conditions" of the virtual twin. The spontaneous preference for collaboration in the virtual reality environment by designers—both "builders" and professional specialists—raises the hope that this technology will become standard as soon as technical conditions allow.

Issues

The experiments also show the negative aspects of working and communicating in virtual reality—specifically in immersive conditions, i.e. when using a headset. It confirms the previously established fact that immersion causes physical discomfort for some people—nausea similar to mild kinetosis. The common denominator of this and other discomforts and difficulties is the mismatch between the action of the body (and perhaps touch), which remains in the physical reality, and the simultaneous sensory, especially visual perception, which takes place in the virtual reality, whose attributes and parameters are fundamentally different from the physical reality. Even one who does not experience the kinetosis thus produced feels (at least initially) discomfort when expected to descend a stair in virtual reality with one's feet on a plane in physical reality or to walk through a wall on the way from one room to another. Certainly, software development will soon provide a partial solution—for example, by making models that have doors that the "visitor" can open with a motion close to that to which he is accustomed, and by walking from room to room through doors rather than through walls as in today's virtual reality applications. Further improvements may come with a habit, and perhaps new versions of headsets will help.

A specific problem is the movement of the user in the vertical direction. Teleportation is mastered, to bow or squat is not a problem—it happens both in virtual and physical reality. It is necessary to unlearn sitting on virtual chairs and seats: unlike physical ones, they do not provide any support for the sitting body. Walking

Figure 7: The Possibility to Discuss a Project in a Passive Viewing Mode in Virtual Reality Between Several Different Stakeholders is a Tool for a More Effective Understanding of a Specific Architectural Solution. Image from the Experimental Verification of Assumptions, Author's Archive

up virtual stairs is "solvable" (only partially) ad hoc: for a particular virtual twin, it is possible (though difficult and expensive) to process a software modification that is activated as soon as the user has a staircase in front of him: if he goes up it, his eyes in virtual reality start to ascend "the stairs" (instead of gradually sinking into the stairs in a similar way to passing through a wall). However, the movement up the stairs still takes place only in virtual reality: the user's feet continue to walk on the flat physical floor.

All these phenomena, however, do not change the contribution of the perception of architecture—a virtual twin in the space of virtual reality. They are just insignificant, sometimes amusing peripeties.

4. Discussion

The promising results of the experimental validation of the complex technology of comprehensive virtual twin of (not yet materialized) architectures tempt us to narrow our focus and concentrate our research and development energies on practical, immediately rewarding goals and tasks. There are many such visible in the R&D presented: their nature is mostly technological—software development, implementation, and

dissemination. However, it would be a mistake to overlook that the existing knowledge in the field, the results of development, and experiments suggest an ambitious assumption of singularity, represented by the phenomena of virtual twins and the open and inclusive public space of virtual reality. This paper presents for discussion possible, very diverse areas of future development that could—should—stem from the singularity. The present list is not intended to be exhaustive: a call for additions is part of the discussion.

Communication, Public Space, Extended Existence

The communication of sociocultural and material values (Habermas, 1981) is the raison d'être and modus vivendi of architecture, which is the communication interface (McLuhan and Lapham, 1994) between man and the world (Heidegger, 2006). The improvement of the quality of communication and the general accessibility of all communicative aspects of architecture is another benefit of the instant creation of architecture in virtual reality and virtual public space: in this environment, even those who have not been able to understand the architectural vision and express their opinion and approach until now, relying on traditional tools, can do so. The number of people who can be together in the virtual public space of a particular project is limited only by the hardware. Without a headset, it is not possible to enter virtual reality: not yet, and even that is not entirely true. Metaverse applications are universally multi-platform. Virtual reality can be entered from a desktop and a mobile phone: it is not the true immerse, but the other attributes of virtual reality—free movement in space in "real size" and free access to every detail of the virtual twin at will, the diachronic perception of the architecture corresponding to physical reality—remain. The possibility of discussing a project in the mode of passive viewing between several different stakeholders is becoming a common practice: it is a tool for a more effective understanding of the issues discussed in a specific architectural solution, and therefore a tool for an effective and quick consensus between the author, consultants and professional specialists, the owner, the investor, the public administration, the public, ... The condition of the unity of the physical place does not apply here: only access to the Internet is the condition of the meeting in virtual reality. The necessary hardware equipment—the headset—is simultaneously improved in terms of comfort of use and quality of experience as well as accessibility. The same limiting conditions also apply, or no longer apply, to meetings in interactive public space—for example, in the virtual reality of Wearrecho: unprecedented possibilities open up.

The options to be provided by the metaverse are unsuspected, and (very likely) no one can predict what all the massive research and development of the Meta project will bring. One can hope that social networks, which now dominate the virtual public space of information and communication technologies and which are mostly killers of time that could otherwise be spent in a more meaningful way, and generators of psychological problems and socio-pathological phenomena, will be marginalized by the "real virtual world" of a parallel, more precisely extended existence of people, communities and societies. The "real virtual world" to come promises to enrich truly our lives: slowly-slowly, we can believe it. Already today, the metaverse hosts a supply of virtual, NFT (https://www.nft.com; https://www.binance.com/en/nft/home?ads=true&utm_source=bing_ads&utm_medium=cpc&ref=TDJYLZ1Y&gclid=39335fb7f52e138ab3713d48567f7f45&_gclsrc=3p.ds&msclkid=39335fb7f52e138ab3713d48567f7f45; https://www.forbes.com/advisor/investing/cryptocurrency/nft-non-fungible-token/) "assets"—values, artworks, and architecture—that are monetized and appropriated, and treated by their creators and owners—in virtual reality—similarly to "real" artworks in physical reality. The effects in the field of architecture and the built environment—apart from the practical, professional ones discussed earlier—are, if possible, even less conceivable, let alone reducible.

It is not only about the fundamentally team-based nature of the architectural design process: architecture is created in mutual communication between authors, communities, society, individuals, stakeholders, and public administrations, ... It is not only about the much talked about participation. The decisive object of architecture has always been the public space—the space of urban communication (Sourek, 2014): always, until the rise of modernity from the mid-18th century onwards, until Marc-Antoine Laugier's *concept of the primitive hut* (Laugiere, 2012) eclipsed public space by speculative form. Public space is the world of our existence, the world in which we live mentally, culturally, and physically: it is not surprising that, along with public space, architecture as a discipline and field has gradually and subtly found itself on the sidelines. The return of public space to the focal point of architects and the revival of *summum templum architecturae* (Vitruvius, 2005) show possible only hand in hand. Humanity, without realizing it, urgently needs architecture to be in the position of *summum templum* again for the sustainability of life on Earth stands and falls with the sustainability of the built environment, and the public space is the backbone of the built environment in the historical sense and in terms of the vitality of the built environment.

Virtual reality is good for space -good for public space. Virtual reality is, as has been repeatedly pointed out, public space by its very nature: it is natural for architects to focus on its space—unless the immediate tool of creation prevents this: but there is no reason why this should be the case. The immediacy of designing architecture in virtual reality is therefore a path not only to higher quality architecture and a sustainable built environment, not only to improved communication in the design process and public acceptance of architecture, not only to increased architectural productivity and reduced construction costs but also—perhaps most importantly—to a return of attention to public space and a renaissance of architecture as a discipline..

Along with humans, artificial intelligence will also inhabit the world of human existence augmented by virtual reality (https://en.wikipedia.org/wiki/Artificial_intelligence; https://en.wikipedia.org/wiki/Deep_learning). It is currently trying to define itself towards architects in a similar way as energy specialists and environmentalists did a decade earlier: although it explicitly rejects it, it tries to replace their work and creation with the parametric generation of designs, especially the layout and operational solutions at the scale of buildings and urban entities. It is necessary to discuss these technologies even if they are declared as just a basis, a quantitative parametric work that saves the architect's capacity to complete it with a creative act (https://medium.com/built-horizons/ai-architecture-4c1ec34a42b8; https://www.autodesk.com/autodesk-university/article/Generative-Design-Architectural-Space-Planning-2 020). Let us not forget that even a banal floor plan is a scenario, the outline of a story: do architects want to produce "stories" similar to those automatically generated by AI applications like SassBook or TL;DR Papers? (https://sassbook.com/ai-story-writer; https://deepai.org/machine-learning-model/text-generator; https://fzone.cz/clanky/nove-vyuziti-pro-ai-slozite-vedecke-texty-pojme-tak-aby-jim-rozumel-i-skolak-3376). The story of Sidewalk Labs' (a subsidiary of Alphabet, i.e., Google's sister company) efforts to solve the AI-led regeneration of Toronto's Quayside area is discouraging: "humans make mistakes, machines don't"—this principle was to be the basis for the design of a new, mostly residential locality that was to be a benchmark of the most advanced contemporary urban development requirements and principles (Hawkins, 2020). The thirty-member collective spent two and a half years collecting data and programming—only to have the project prematurely terminated due to escalating disagreements between Sidewalk Labs, the city government, and city residents. The public, including potential future residents, rejected the exchange of socio-cultural values—privacy, individual access, (future) grand

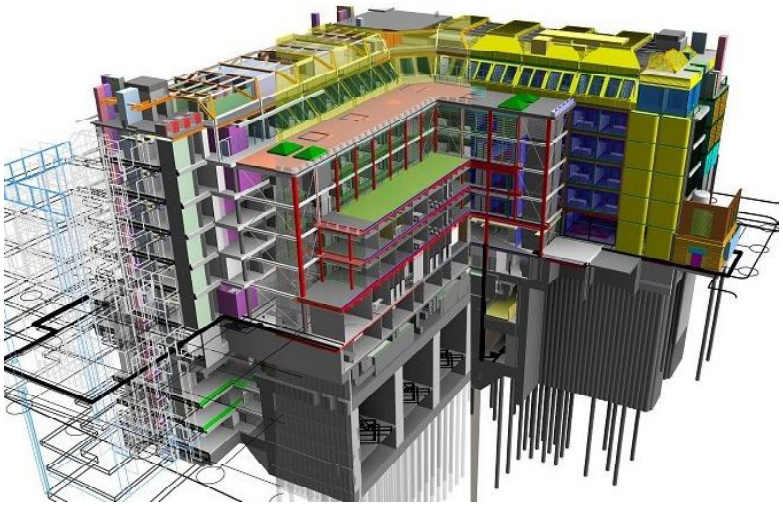

Figure 8: On the One Hand, the Need For Free Poietic Creativity and the Optimizing Benefit of the Parameterization of the Structural and Technical Solution of the Material Representation of Architecture On the Other Create A Schism. Its Solution Is the Possibility of A Smooth Transition In the Intertwined Processes of Architectural Design and Its Structural and Technical Solution From the Environment of Virtual Reality To the Environment of Parametric Tools and Back Without Losing Or Deforming the Spatial and Shape Solution of Architecture and Its Attributes. Illustrative Image, Author's Archive.

and everyday experiences, and some freedom—for material comfort dictated by the algorithm. Either way, architects must not stick their heads in the sand in front of artificial intelligence: artificial intelligence is another of *the foundations of the yet-to-be-born technological age that needs to be grasped by thinking* (Augstein *et al.*, 1976)—just like virtual reality. The positive results of grasping can then most easily "materialize" in virtual reality.

It is hard to imagine a valuable parallel, extended existence outside of the spatial—virtually spatial—framework, outside the framework of virtual architecture and architectonized public space. The architectural framework of an extended existence is unlikely to remain a collection of virtual twins of architecture designed for the 'real' physical world, albeit not (yet) materialized. The architecture of the virtual world emancipates itself—to eventually influence the physical one.

Architectural Theory

The contribution of virtual twins of architecture and the opportunity to immerse in "their" space can also be hoped for in the field of architectural theory. Such a contribution can begin by increasing the attractiveness of a discipline that lacks (with few exceptions) developments, supporting ideas and their systematic elaboration, and thinkers to engage responsibly and productively. Veselý (2004), who died before he could develop his work into a form the architectural practice could directly benefit from, began to rectify this deficit in the new millennium: the first starting from Giedion's work until the end of World War II (Giedion, 1967; 1948), at the latest from Schulz (1985). Everything else that has been produced in the last half-century is at best only fragments, lacking the much-needed coherence, or philosophical works—too philosophical to support the practice.

Perhaps, this situation stems at least partly from difficulties in accessing authentic architectural attributes. Most of those who attempt to articulate a theory lack elementary craft (at least theoretical) training. In approaching the material aspects of architecture—from the point of view of its creation in particular—they are laymen, in fact. If immersion into the virtual twin space of virtual reality helps the general public to know, understand and grasp architecture, it should help the adepts of architectural theory all the more. Particular attention should be paid to the virtual reality space as an environment in which—unprecedentedly—experiments can take place to test the hypotheses of a new theory of architecture.

In any case, efforts to articulate current architectural theory should not bypass the virtual space: if only because it will (also) be giving birth to the attitudes and ideas of the movers and receivers of the development of the built environment and public space, of new architectural achievements.

Economic and Societal Implications of the Development of Architectural Virtual Twins´ Technologies

From time immemorial to the present day, the architect's capital has been his imagination and creativity, as well as his technical and organizational knowledge and skills. But everything was only in his head: it is hardly possible to invest directly in such a "technology". This makes architectural practice the most under-invested among fields of activity that have both daily and long-term, immediate and mediated major impacts on the lives of people, communities and municipalities, and society as a whole..

Such a statement is likely to elicit raised eyebrows, if not disapproval, "and what about all those Autocads, Revits, Archicads, and also 3D maxes, Lumions, ...?" First of all, these are tools for planning structures to materialize architecture, not architecture itself—this has already been pointed out. Moreover, the whole field of "Computer-Aided Design" (CAD) was developed primarily to serve the needs of mechanical design and engineering, this field has long been the driver of demand for software development, and together with product design, which joined later, still dominates today. This "origin" still influences the functionality of Autodesk Revit today, as well as Archicad: they can model structures, but they are not interested in space, and their parameterizing paradigm often harms architecture instead of benefiting it. And Lumion? The latter, in turn, is the "melon" of the game software industry, which could no longer look past the clumsiness of CAD visualization programs. This whole area, it shall be recalled, is the materialization of Vesely's (2004) *problem of creativity in the shadow of production.*

The underinvestment of architecture stands out in the context of the wave of start-ups and angel investing, which can be equated with the beginnings of industrialization in the 18th and early 19th centuries, and which has so far left architecture "sitting in the corner". In the 1990s, the dot.com era changed people's lives and the

global economy: importantly, from the perspective pursued in this paper, it was far from being only the work of computer enthusiasts, programmers and engineers alone: without trillions of dollars of investment, the dot.com bubble would not have inflated, but more importantly, once it burst, computers, programs, applications, social networks, and information and communication technologies would not have become an integral part of the economy and our lives. A decade later, clean and renewable energy enthusiasts have managed to make their way into investors' sights: and again, thanks to a combination of techies and big money, photovoltaic plants of all sizes are now as commonplace as heat pumps, wind farms, biomass incinerators and the like. This time, private financial resources have been joined by public resources—state, European, Norwegian, Swiss, ...: the reason is obvious, we don't want to "choke" or freeze when the coal and oil run out ... Just "before the covid", thousands of experienced "start-uppers" started to reorient their businesses. "Clean-tech", clean, and renewable energy became "business as usual", and opportunities to build "unicorns" moved into the "climate-tech" sphere. Under the banner of climate change mitigation, an era of decarbonizing everything has emerged: from sneakers made from coffee grounds to textiles and leather substitutes produced by micro-organisms, to low-carbon cement or steel made without fossil raw materials. As the experience of astronomical profits from previous eras of start-ups met with an almost universal acceptance of the threat of climate change, another round of the race to "first come, first served" began.

Today, virtual reality shows the way to restart the development of architecture and the built environment for the benefit of improving the quality of life of people and society, for the benefit of the sustainability of life on Earth. But we must respect economic realities and the experience of the waves of angel investing of the past decades. It is not about the development of individual tools, it is not (only and certainly not preferentially) about Wearrecho, it is not about "advertising" to pull money out of the pockets of those who "fall for it": it is about the development of a whole serious field. And for the sake of it, architects need to understand that they can't get it off the ground on their own or with a small community of IT developers. They must make a common thing that "their" problem of outdated, unproductive, and inefficient working tools is a matter of public interest. They must show that only in a virtual reality—nvironment—only with tools unparalleled so far—they will be able to design and create architecture and public space more efficiently, more productively and in a way that best meets the needs of not just war-ravaged Ukraine, not just their eight billion end clients, not just a climate change threatened planet.

Industrialize the Architectural Profession Finally

Virtual public space, and especially virtual reality environments and technologies, put the architectural profession on the threshold of a revolution that promises to optimize the processes of architectural design and the design of the construction works that materialize architecture and to enable unprecedented smoothness and quality of communication between the participants in these processes—architects, owners, investors, project managers, planners, building contractors, and the public with each other. Is the architectural profession ready for such a revolution?

Today, the architectural profession operates in a competitive environment. Perhaps since the end of the so-called long (19th) century (Zatloukal, 2002) perhaps since the advent of architectural modernism, probably in connection with architecture's loss of its status as *summum templum* (Vitruvius, 2005), the profession of architecture has lost (sort of) exclusivity. It has become one of the modern crafts—a field of business for which competition is an existential attribute.

In 1884, Toynbee (2011) explained that the essence of industrialization is the replacement of the medieval regulation of production and distribution by competition. Toynbee's brilliant and valuable insight has never attracted the attention it deserves: yet, since the 19th century, many fields of business have operated faithfully in its spirit—but not architecture. The architectural profession has not yet managed to industrialize and, nearly a hundred and fifty years after the publication of Toynbee's Lessons of the Industrial Revolution remains a medieval craft. Computers on architects' desks do not change this: their craft is bound together by the paradigm of guild organization, though an unconscious one.

Today, the profession of architect is, like the profession of physician, lawyer, executor, tax advisor, ... *a freelance profession to which most states attribute special competence and general responsibility due to the serious impact of its practice on the protected interests of individuals and the public interest* (https://cs.wikipedia.org/wiki/Svobodné_povolání, https://fr.wikipedia.org/wiki/Profession_libérale). Of all these professions, the contradiction of the guild paradigm of the practice of the profession and the public interest is most pronounced in case of the architectural profession—and the negative impact of such a paradigm on the real and eminently legitimate interests of society is the most significant, ultimately the most tangible.

As a rule, the law derives *the special competence of the freelance profession* from higher education, previous experience under the supervision of a qualified colleague, and passing an additional examination—authorization, attestation, bar examination, ... The state considers such competence so high that it does not feel capable of verifying it; therefore, it establishes self-governing professional organizations—chambers—to which it delegates, among other things, the exclusive right and duty to verify such competence. The similarity to medieval guild regulations (Winter, 2022) and the process of *apprenticeship—journeyman's examination—journeyman's practice in the master's workshop*—and finally, if the master sees fit, *master's examination*—is obvious, and is probably the starting point of the guild paradigm that is, more or less inherent in most of today's self-governing professional organizations—chambers of architects often in the first place. The application of the guild paradigm in architectural practice is as brutal as disguised.

The situation of architects is further complicated by the nature of their product—the architectural design—which the market, unlike the product of a lawyer or a physician, perceives as *a commodity—an asset that the customer has bought and which has become his property, he can dispose of it more or less without limitations, he can store it and its nature remains once and for all given, he can (to some extent) divide it into parts and he can even resell it* (Bannack *et al.,* 1984). The market partly includes the creative aspects of architectural design in this property, partly omits them, and does not bother with the declared *special competence and general responsibility* of their author concerning *the protected interests of individuals and the public interest.*

The interplay of all these, and perhaps other circumstances, too, has caused the architect to enter the market today, as a rule, by presenting a comprehensive concept to the client, the owner—the customer, who has been taught by the market that he can choose from a wide range of goods to meet his expectations, and he carries this formula over into his relationship with the architectural profession. It is called *architectural competition*: few labels are more misleading—architectural competition has little in common with *Toynbee's industrial competition*. An architect's "commodity" is always, by its very nature, a unique "custom" product: if the architect does not sell it to the customer to whom he presents it, it remains unsold once and for all, and all the effort and expense the architect has expended in creating it is wasted. Among the freelance professions (not to mention the other crafts), he is the only one who does this. He is the only one that the market expects to offer a compensatory, unique, and "one-use" product in free competition in a market that cannot make rational decisions because it is objectively unable to recognize the qualities of the product and evaluate it. Remember: the state itself has decided that the profession of architecture is so demanding that it is not in the power of the state to decide who is qualified for it and who is not. Deciding on the quality of the specific performance of such a profession is undoubtedly even more demanding.

Since the 1960s at the latest, self-governing organizations of practicing architects worldwide have set and maintained fundamentally biased conditions of practice that are economically and reputationally destructive to the profession as a whole and to individual architects. They both lead and force their members to procure, at great expenses, highly complex products whose acceptance and perhaps—not always!—adequate remuneration, are decided not by the market, but (to a significant extent) by subjects prone to decisions that are biased in many respects.

The problem starts with the fact that the principle of architectural competition is—due to the requirement of anonymity and the resulting inefficiency of consultation—blindfolded shooting at a moving target. It is exacerbated by the irrational relationship between the price of risk and the amount of potential gain: with few exceptions, even the first prize in an architectural competition does not cover the cost of developing the competition proposal. Above all, the objectivity, and hence the quality, of the decision-making of competition committees cannot be ensured even by the mandatory representation of so-called independent committee members from among authorized architects —"guild masters". First of all, the quality of architecture is inherently poetic (https://en.wikipedia.org/wiki/Poiesis)—inevitably subjective. Competition juries do not hesitate to subscribe to subjectivity in specific cases (Hlavní, 2021): they overlook, however, that *poetry*, and hence architecture] *is authentic only if it is shared poetry* (Heidegger, 2000). Second, it is a proven fact that *power corrupts* (Whinston *et al.,* 2022). The power within a closed—for example, professional—community corrupts doubly. The contribution of this phenomenon to the stagnation of the guild crafts in the Middle Ages is well known and proven: conflict of interest in case of a member of a competition committee that is a member of a competing profession is not an individual failing but a systematic threat, the fulfilment of which by a protégé's decision is the rule rather than an exception. The tendency to favor affiliated persons is not necessarily the only one: the tendency to exclude other than the usual 'tried and tested' solutions is equally counterproductive: on September

18, 1829, the locomotive *Rocket*, designed by son and father Stephenson, won the competition to provide freight wagons on the Liverpool and Manchester line, exceeding the specified transport parameters by 40% and doing better than its competitors in this respect. At the same time, its performance proved the leading transport experts of the day wrong when they recommended that the service should be provided by twenty-two stationary engines (Wagner, 2021). The leading transport experts could not have been more wrong.

Finally, a commercial competition for the lowest price cannot be a regular one either, since in case of architectural and design work it is essentially a "sale of a pig in a poke". An unambiguous price is inevitably opposed by an indeterminate specification of the 'goods' or performance. Neither the bidder, let alone the customer, know what quality of the final product—the built environment entity—one will eventually create and the other will obtain; neither can control the parameters of the product in the process of its conception and creation; nor can they measure its final quality. The 'stumbling blocks' that often accompany the preparation of projects whose designer and / or planner has been selected in one way or the other are incompatible with both responsible asset management and a reasonable level of loss that can accompany the search for an optimal outcome. In retrospect, even projects that have been 'quiet' will not generally stand up to scrutiny as proof of the correctness of the selection: their 'quiet' often turns out to be the result of the indifference or surrender of the (usually public) customer.

At the heart of the problem of the dire situation of architectural practice is uncertain, obscured, the barely identifiable relationship between the representation of architecture (and the construction that is to materialize it) in the design, concept, or promise that an architect presents when bidding for a commission, and the future reality of the materialized architecture and the constructed structure. The quality of this relationship, and hence the quality of the message of the competition proposals, fundamentally challenges the dogma of the greater objectivity of architectural competition compared to selection by price; other criteria applied in practice—deadline, references, ...—prove even less relevant. The risk of an erroneous selection is high in either case. In both cases, the same nature of risk is involved—the selection of the future architecture (and its construction substance) not according to its actual attributes, but only according to its representation at the very beginning of the design and planning process. Whether one selects by a representation of price or by a representation of sketches and calculations, the likelihood of a correct, objective selection is woefully low.

Awareness of the dire conditions described above is beginning to emerge: for the time being, however, it relates exclusively to the socioeconomic conditions of the profession (Wagner, 2021; Deamer, 2020; Conklin, 2019; Stouhl, 2021; Easterling, 2014; Berardi, 2005). The public, municipal and state administrations are unaware that they result in economic losses and, what is worse, substandard shaping of the public space and the development of the built environment: ultimately, sustainable development is torpedoed. The public administration should therefore have a fundamental interest in rectifying the situation of the industry—and within it, the craft.

The virtual twin and the transfer of the cognitive and evaluative process to virtual reality offers an obvious solution: why decide according to representations—any representations—when it is possible to decide according to real attributes—to decide according to a compressive set of attributes instead of a fragmentary representation. Instead of the cost of the risk of a wrong choice, virtual twin puts the cost of its elaboration or purchase. These are today (so far) higher than the cost of preparing a bid or the usual competitive proposal, but orders of magnitude lower than the value of the losses due to mis-selection. It remains to be decided whether these costs are to be borne by each of the architects competing for the contract or by the client—or whether they are to be shared, perhaps in proportion to the financial volume of the project in question, or concerning the value of the customer's benefit, expressed as the difference between the value of the best solution and the solution chosen haphazardly or even according to counterproductive criteria. If the technology of virtual reality and virtual twins had been available in the early 1800s, son and father Stephenson would not have had to build the Rocket out of steel and have it race on the iron tracks at Rainhill to show that their solution was the best. The competition could have been run by virtual twins of competing machines in virtual reality with the same result: there would have been no reason why the customer would have made a different decision from the one he made based on the "physical race". Conversely, if the Liverpool and Manchester Railway Company made a decision based on the representative solutions put forward, it would probably have heeded the recommendations of the leading experts of the time (https://en.wikipedia.org/wiki/Stephenson%27s_Rocket) and the freight wagons between the termini would have continued to be pulled by ropes wound on one of the two-and-twenty stationary winches. In time, the company would have discovered that it had made the wrong

choice—but the investment costs would have already been spent, largely wasted, the traffic would have been unnecessarily slow, and it would have hampered the region's economy. But the development of rail transport, in general, would be stymied: the implementation and therefore 'validation' of an inappropriate solution would not only negatively affect the UK economy—ultimately slowing the growth of living standards and social and cultural development on a global scale. The whole of society would pay the price for a bad decision, which would have had to be bad when representatives competed against each other and against reels instead of real solutions—locomotives. The same thing happens today (and every day) in the cases of commissioning architectural design and built environment development projects when bidders and representatives of future solutions compete amongst themselves in the way that architects' guilds and general legislation advocate.

Moreover, the public space of virtual reality will be open and inclusive—recall. Thus, the public could have access to virtual twins of the designs competing in the competition: access as good as those selecting the most appropriate solution. There is no reason why all the documentation for the selection of the most appropriate, best proposal should not also be located and accessible in the virtual public space. Is it possible to imagine a better social control of the quality of the competing designs and of the decision to select the most suitable ones—concerning the commissions and buildings of public procurers, but also of private procurers, when architecture, given its mutually constitutive relationship with the public space, is an inherently public matter? And isn't this another very compelling reason for the development of virtual twin technologies of architecture and the built environment (entities) and virtual reality technology in general?

5. Conclusion

The work presented a broad framework of the virtual reality phenomenon in the context of architecture, built or synthetic environments, and public space: on the one hand, the state of research and development in the field of tools for designing architecture and planning constructions using virtual reality, and the state of the field of architecture and the profession of architecture that virtual reality technology encounters; on the other hand, perspectives on interpersonal communication, public space and the extended existence of man and humanity, perspectives for architectural theories, economic and social contexts for the (further) development of virtual twin technologies of architecture, and perspectives on the industrialization of the profession of architecture. The intersection of the two spheres of work shows the singularity that embeds a software tool, rather a complex computer environment of virtual reality space, in which virtual twins of architecture and construction structures materialized or to be materialized in the real world exist and are created by architects and construction planners, visited by them, prospectively "inhabited" by stakeholders of architectural projects and projects of development and transformation of the built environment, to participate in their creation and transformation, get to know them and get acquainted with them, communicate (not only about them) with each other—also with the support of artificial intelligence. This complex environment is an open and inclusive metaverse: the intention is to connect it—as a whole or in the spaces of individual twins—individual projects—to the global Meta network. The stakeholder can then be almost any person, the global society as a whole, and specific communities and societies.

The paper shows also particular results of research and development of a software tool, or a complex computer environment of virtual reality space, which aims to fulfill the presented singularity. *Wearrecho* (the proprietary name of the tool) was experimentally verified in the development version in the studio lessons of the Architecture and Civil Engineering program at the Faculty of Civil Engineering of the Czech Technical University in Prague: the results of the experiment, presented in the third part of the paper, are overwhelmingly positive. They confirm the benefits in the field of authentic understanding of architecture and architectural spatial creativity, the rise of the quality of designs and solutions, as well as the economic benefits of working in the *Wearrecho* environment in the form of increased productivity and work efficiency.

The positive results of the experiment argue for continued research and development of the tool and space. In autumn 2022, the first phase of research and development is being completed, the objectives of which are specified in the third part of the thesis. In terms of the functionalities of the software and computing environment to be developed, the following objectives are set for the next phase, which is to start in 2023 and is expected to last two and a half to three years:

- Increasing the stability of the existing functions and environment, scaling up the cloud workplace for an order of magnitude increase in the number of users, regulating access at different levels of functionality;

- *Wearrecho* multiplatform solution: desktop, augmented reality, and mobile versions, remote access from alternative devices;
- Expanding the possibilities and comfort of inserting components from other environments into the virtual reality project space;
- Equipping virtual twins with the materiality of structural design—gravity, load-bearing capacity, loading of structural elements;
- Equipping the virtual twin with structural statics attributes, connecting static calculation tools;
- Creating specialized working tools and basic libraries for landscaping and gardening design and planning;
- Creating specialized working tools and basic libraries for interior design and planning, and product design and planning;
- Connecting geodetic data tools and files, GIS and spatial planning tools and files;
- Connecting publicly available data structures on existing terrain configurations and the built environment, OpenStreetMap, and others;
- In general, the goal is for Wearrecho virtual reality to become a working and communicative interactive front-end and back-end interface between virtual reality objects and structures on the one hand and the parametric tools of the individual disciplines involved in the design and project processes and the preparation of materials;
- Connecting virtual spaces of (individual) projects to the Meta network.

Continuing development will be accompanied by systematic building and evaluation of the user experience and implementation of its findings. The author of this thesis will continue to be the principal investigator of the research and development, and the team of existing researchers will be strengthened and joined by the staff of the Faculty of Civil Engineering of the Czech Technical University in Prague. User experience will be gained in the environment of the architectural studio of the author of the paper, in other professional organizations (including public administration), in university teaching, and in the academic environment in general.

It remains open for further stages of development to solve the problems of the inconsistency of sensory perception and movements and body states of the virtual reality user / visitor of the virtual space and equipping the virtual space with attributes of other sensory inputs—mainly acoustic or tactile.

The overlaps of the application of virtual reality outside the field of architecture and its materialization can be a subject of the next phase of research and development. Preliminarily, this is to include

- development of construction systems for modular and otherwise industrialized construction;
- training and implementation of work activities, health and rehabilitation care, sports training;
- monitoring and managing the performance of work and service activities;
- development of computer games, kits, ...

The plan avoids mechanical and electrical production and the monitoring and control of factory production: in these areas, the use of virtual reality is already well developed.

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