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Special Issue on Internet of Digital and Cognitive Reality: Applications and Key Challenges

Péter Baranyi

The recent co-evolution of human society and technology has led to a new digital era, represented by a variety of technologies including Virtual Reality, Augmented Reality, Digital Twins, Artificial Intelligence, 5G networks, besides the "classical" Web 2.0. As these technologies begin to merge together via unified applications and digital environments characterized by the disappearance of the borders between the physical / natural and the digital, as well as between representation and simulation. This leads to highly contextual and dynamic entanglement with humans, hence, a qualitatively new kind of reality can be expected to emerge. This reality, referred to as Digital Reality is characterized by the blended combination of artificial and natural cognitive systems to cover the specific requirements of the environment. Thus, the Digital & Cognitive Reality emphasizes the goal-oriented unification of the physical and digital realms as a context-driven whole. At the same time, the networked transmission and sharing of physical-digital contexts can be expected to become a key area of interest, leading to the notion of Internet of Digital & Cognitve Reality.

Based on the above, Digital Reality (DR) and Internet of Digital Reality (IoD) can be defined as follows:

“A Digital Reality (DR) is a high-level integration of virtual reality (including augmented reality, virtual and digital simulations and twins), artificial intelligence and 2D digital environments which creates a highly contextual reality for humans in which previously disparate realms of human experience are brought together. DR encompasses not only industrial applications but also helps increase productivity in all corners of life (both physical and digital), thereby enabling the development of new social entities and structures, such as 3D digital universities, 3D businesses, 3D governance, 3D web-based digital entertainment, 3D collaborative sites and marketplaces. The Internet of Digital Reality (IoD) is a set of technologies that enables digital realities to be managed, transmitted and harmonized in networked environments (both public and private), focusing on a higher level of user accessibility, immersiveness and experience with the help of virtual reality and artificial intelligence.“

Péter Baranyi established the Cognitive Infocommunications concept around 2010. It is a scientific discipline today focusing on the new cognitive capabilities of the blended combination of human and informatics. It has an annual IEEE International Conference and a number of scientific journal special issues. He invented the TP model transformation which is a higher-order singular value decomposition of continuous functions. It has a crucial role in nonlinear control design theories and opens new ways for optimization. He is the inventor of MaxWhere which is the first 3D platform including 3D web, 3D browser, 3D store, and 3D Cloud. His research group published a number of journal papers firstly reporting that users get 40-50% better effectiveness in 3D digital environments. These results got a very high international impact within a few years.

Special Issue of the Infocommunication Journal

Evolution of Digitization toward the Internet of Digital & Cognitive Realities and Smart Ecosystems

Gyula Sallai

***Abstract*—The evolutionary phases and perspectives of the digitization process are presented focusing on the milestones of technological evolution. The digital convergence of communications, information technology and media, the concept of cognitive infocommunications, the extension of networking by Internet of Things, the immersive technologies as augmented reality and virtual reality and the artificial intelligence have relevant role in the shaping the concept of the Internet of Digital & Cognitive Realities (IoDC) and the Smart Ecosystems as Smart Cities and Smart Factories.**

***Index Terms*—artificial intelligence, augmented and virtual reality, cognitive infocommunications, digital convergence, Digital Ecosystem, digitization process, Future Internet, Internet of Things, Smart Ecosystem, Smart City**

I. Introduction

Figure 1 shows the evolutionary phases of the digitization process [1].

Over the past 40-50 years, the unbroken progress of microelectronics has digitized communications and media technology, and has integrated communications, information technology and media. This process is called digital convergence, which includes not only technology but also the convergence of services and relevant markets and affects their regulation [2]. For unified digital communications of digitized contents, the Internet Protocol has been the most successful technology, which has become a global networking technology and has also proven useful in information processing and content management.

The process of digital convergence has led to the emergence of Digital Ecosystems, in which the synergic opportunities resulting from convergence and the extension of networking, the networking of objects, the Internet of Things (IoT) have played a main role.

Over the past decade, the goals of Internet development have largely been achieved, and solutions have strengthened. The most dynamic developments have been in the immersive technologies (augmented and virtual reality, AR/VR) and the artificial intelligence (AI). The concept of the IoT is broadening and beyond the concept of the Internet of

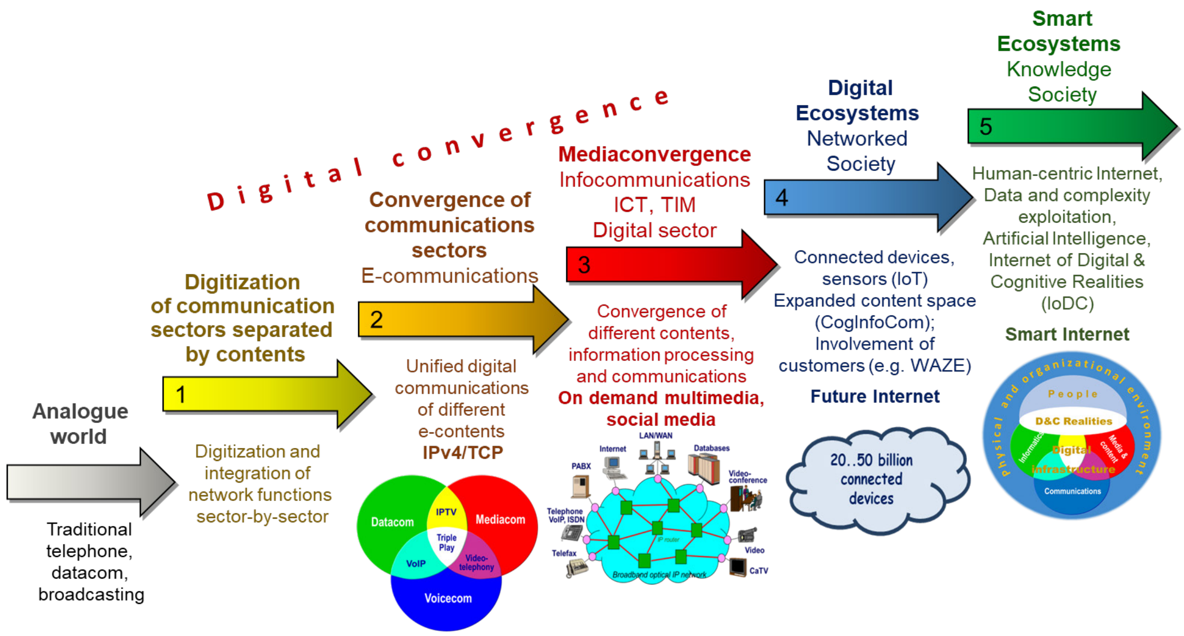

Fig. 1. Evolutionary phases of the digitization process

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This article is an extended version of the keynote paper of the First IEEE International Conference on Internet of Digital Reality presented at 23 June 2022. The conference discussions have concluded that the term “Internet of Digital Reality” is suggested to be renamed as “Internet of Digital & Cognitive Realities” to better refer to cognitive aspects and human factors.

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Everything (IoE), which unites the Internet of people and objects, the new concept of the Internet of Digital & Cognitive Realities (IoDC) already encompasses the networking of the widest range of cognitive entities, and consciously builds on and integrates AI and AR/VR [3][4]. The concept of the Digital Ecosystem is evolving into a Smart Internet-based Ecosystem (Smart Ecosystem) that exploits these opportunities, with three distinct holistic appearances for the time being: smart cities, smart industrial systems and, in the longer term, smart agricultural systems.

The five evolutionary phases of the digitization process are detailed below.

II. The Phases Of Digital Convergence

We can identify three main overlapping evolutionary phases of the digital convergence.

In Phase 1, the digitization and integration of network functions was implemented separately for each communications sector. Among the network functions, first the transmission, then the control, and finally the switching technology have been digitized.

In Phase 2, integrated, unified digital communication of different contents was created. Voice, data, text, image, video, or other media content can be efficiently transmitted when digitized and combined into a digital stream. Horizontal convergences and some integration of the services, networks and terminals can be identified (Figure 2) [2][5]. A unified communication sector has emerged, which is formally called electronic communications. In deploying these horizontal convergences, uniform regulation was introduced for e-communications in the European Union [6].

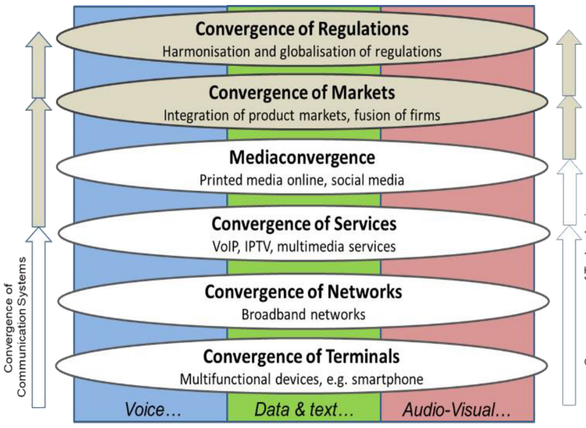

Fig. 2. Horizontal levels of the digital convergence

Phase 3 is the digital convergence of e-communications, information processing and digitized media sectors, providing synergic convergent areas as telematics, mediacommunications, mediainformatics and the area of full integration. Figure 3 illustrates the relation of the basic sectors (represented by blue, green and red primary colors according to the additive RGB color model) and the convergent areas by their combination (represented by cyan, magenta, yellow and white). There are new terms as:

- communications are expanding into *infocommunications (InfoCom)* by encompassing areas compounded with communications [7][8];
- the concept of *Information and Communication Technology (ICT)* is emerging as a union of information technology, communications and the convergent areas [9]; and
- *a unified digital sector* (so-called Telecommunications - Information technology – Media, TIM sector) is shaped, including mediaconvergence, the integrated digital management of various electronic and non-electronic contents [10][11].

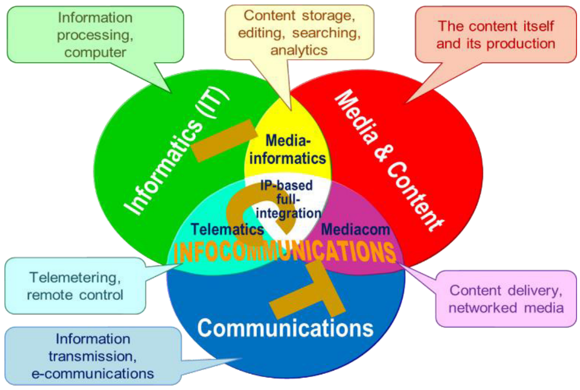

Fig. 3. Convergence of Communications, IT and Media

Internet Protocol version 4 (IPv4/TCP) has become a fundamental technology for a global network and has also been accepted in information processing and content management [12]. As a result of convergence processes, the Internet is emerging in all areas of society and the economy, an integrated ICT infrastructure is established, which is socialized through the services and applications built on it. Users are no longer just consumers of digital content, but can control where, when and how they consume content and participate in the creation and distribution of digital content, becoming members of a digital community.

III. Internet of Things and Digital Ecosystems

The process of digital convergence was leading to the emergence of Digital Ecosystems, the concept of which was first mentioned in 2002 [13] and then formally laid down by the World Economic Forum (WEF) in 2007 (Figure 1, Phase 4) [10]. In addition to the synergies arising from digital convergence, the extension of networking, the networking of objects, *the Internet of Things (IoT)* [14] and the new Internet objectives, which respond to the challenges posed by it (Figure 4) [15][16], played key roles in the creation of Digital Ecosystems.

At the same time, advances in human-oriented technologies have also led to an expansion of the range of handled content with cognitive contents (gestures, emotions, perceptions), allowing interaction of human and artificial cognitive abilities, and resulting in new types of cognitive entities and human ICT technologies such as *Cognitive Infocommunications* (CogInfoCom), immersive technologies (AR/VR) [17][18]. A multitude of Internet-based services have been implemented, with some services seeking to actively engage users (crowdsensing, community perception, e.g. WAZE).

The objectives for the further development of the Internet have been brought together in the concept of *Future Internet,* resulting in relevant new Internet functions and solutions [19][20][21][22]. Fig. 4. shows the objectives of the Future Internet research, as service, resource, data and environmental awareness, as well as societal awareness, and the ultimate goals, the smart applications.

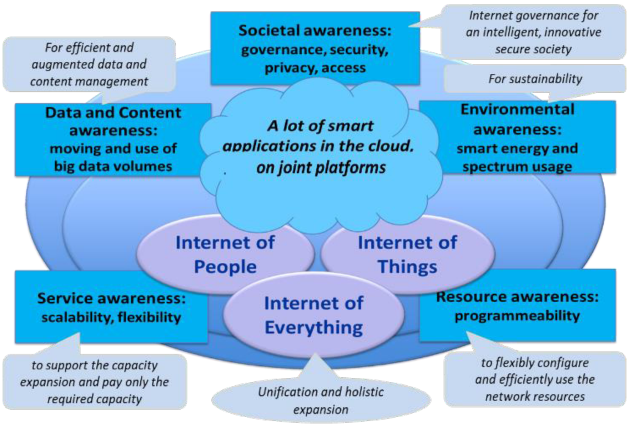

Fig. 4. Future Internet concept and objectives

Digital Ecosystems are created and evolved for some useful purposes, and their interconnected components are:

- *the digital community:* a community of digital users (cognitive entities) consuming, producing and exchanging digital content, whose members can be accessible persons, objects/things and organizations (economic, government and civil organizations);
- *the digital infrastructure* (technical environment), which enables interaction between the members of the digital community, facilitates the collection, processing and sharing of data.

The Digital Ecosystem thus symbolizes the symbiosis of digital infrastructure and the digital community, their mutually beneficial coexistence, and, from an engineering point of view, the union of the technical world and its environment [10]. The concept of Digital Ecosystem has been borrowed from biology, given that their functioning shows similarities. Digital Ecosystem models are based on knowledge from the ecosystems of living things, such as the cooperation and competition of different beings and the role of the environment in which the ecosystem operates and is affected by its functioning. The general model of Digital Ecosystems is displayed in Figure 5, which shows organizations in addition to the natural and built environment (together: physical environment), both as organizational users and as an organizational (business, administrative and civic) environment.

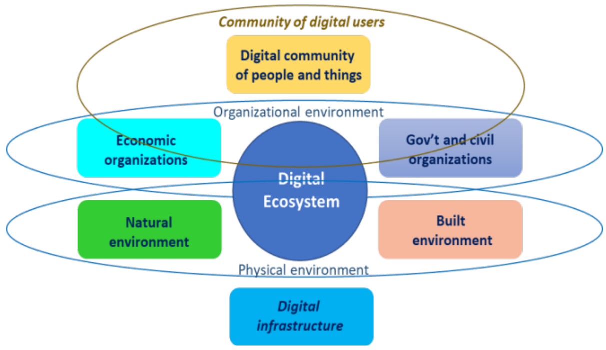

Fig. 5. General model for Digital Ecosystems

The concept of the Digital Ecosystem has unfolded recently. Online marketplaces first appeared, e.g. Amazon, then application support platforms were born, e.g. FIware. Deeper digital integrations in some areas, so-called verticals are formed, e.g. automotive industry, logistics, healthcare, pharmaceuticals, finance. Sometimes the term ecosystem refers to a set of IoT solutions, or e.g. a range of integrated solutions for smart home. The Digital Ecosystem has first emerged in a holistic approach under the names as digital, intelligent and smart cities, smart factories [23][24].

IV. Internet of Digital & Cognitive Realities

Over the past decade, the objectives of the Future Internet have been largely achieved, and the solutions have been strengthened (Figure 6).

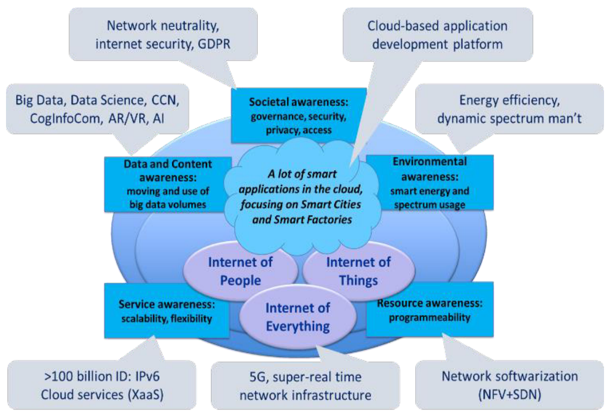

Fig. 6. Future Internet solutions

The IoT is still a driving force, we have seen tremendous developments on the field of sensor networks. 5G network systems integrate several new concepts (cloud-based environment, NFV - network functions virtualization, SDN - software-defined networks, etc.) and have become a key technology for Future Internet-based solutions. Data science, which grows out of the Big Data phenomenon, is leading to a wider spread of data analytics. Augmented and virtual reality (AR/VR) techniques are matured, their widespread use in industry, commerce and education is emerging, the hitherto hidden layers of human capabilities come to the fore, and the concept of the cognitive entity expands with their involvement [17]. The name Digital Ecosystem is increasingly being replaced by the name Internet Ecosystem, which more aptly expresses the Internet-based implementation, and the networking and social character.

However, the most dynamic developments are in the field of artificial intelligence (AI), especially in the field of artificial narrow intelligence (ANI). While in 2015 the IoT was still at the top of the Gartner's "Hype-cycle" curve, in 2017 the focus is already on Deep Learning and Machine Learning, which have been estimated to take 2–5 years to become widespread (Figure 7) [25]. The Hype curve of 2019 also featured AI-related technologies that directly help to build Digital Ecosystems, such as Digital Twins, Knowledge Graphs, DigitalOps. The Hype curves of 2020 and 2021 are also dominated by new AI solutions, signaling the proliferation of AI platforms and the involvement of AI in software development (AI-augmented software engineering) and, in the long run, in design and innovation [26].

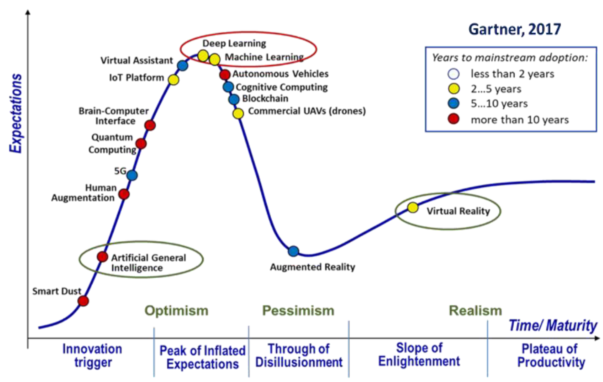

Fig. 7. Hype Curve for emerging ICT innovations in 2017

The concept of IoT is also expanding, and beyond the concept of the Internet of Everything (IoE), which unites the Internet of people and things, *the Internet of Digital & Cognitive Realities* (IoDC) already encompasses the networking of complete digital realities, including the widest range of cognitive entities such as avatars, digital twins, 3D collaborative sites, 3D marketplaces and consciously building on and integrating AI and immersive AR/VR technologies [3][4].

Towards 2020, the planning of the next generation of Internet (temporarily called *Smart Internet*) has begun intensively, the objectives of which include [27][28]:

- the use of artificial intelligence, the exploitation of data in general, which can lead to the widespread adoption of smart, innovative solutions;
- enhancing the human centricity of the Internet, the key points of which are significantly improving the security of the Internet and the protection of privacy, and
- digitization of manufacturing processes, which could trigger a new era of production.

V. Smart Ecosystems

With these capabilities, including IoDC, the Digital Ecosystems are evolving toward Smart Internet-based Ecosystems, shortly *Smart Ecosystems* (Figure 1, Phase 5) for which now three universal, holistic examples can be identified: Smart Cities, Smart Factories (smart industrial systems) and, in the longer term, Smart Farms (smart agricultural systems).

Figure 8 shows a vision of holistic Smart Ecosystems with their six key functional areas as strategic components. Each key area is supported by a wide range of smart solutions. The upper, cardinal key area is related to the fundamental goal of the ecosystem. The other key areas represent the associate energy, mobility, environmental and managerial functions, and the joint ICT background. Figure 8 also indicates the overall role of smart digital infrastructure [29].

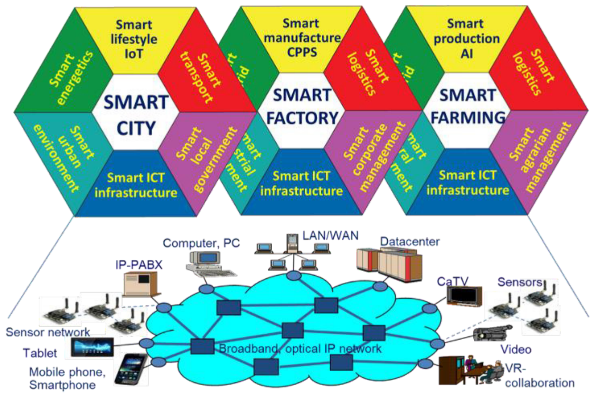

Fig. 8. Hexagonal model of holistic Smart Ecosystems

Smart Cities respond to the challenges of urbanization. The concept is based on IoT and the active involvement of customers and completed using AI and AR/VR methods. A Smart City is obviously characterized by a multitude of Smart City applications, but the concept presupposes the integrated implementation of smart applications and its functioning as an ecosystem. The impact of the transformation process extends to all areas of our lives, environments and sustainability [27]. The key areas as strategic components are smart lifestyle, smart energetics, smart transport, smart urban environment, smart local government and smart ICT infrastructure. Figure 9 shows the interpretation for each Smart City key functional area [30].

A city (as collective term for metropolis, town, district, township, village, region, etc.) can be considered a Smart City Ecosystem if the goals – depending on the nature of the city – affect all key areas, and the goals are achieved with the help of smart ICT solutions by:

- integrated management of city resources and solutions, based on a joint digital infrastructure,
- adaptively, using the possibilities of real-time data control,

- environmental awareness, energy efficient, sustainable way,
- social inclusion, active participation of the community, involving its stakeholders,
- economical self-supporting, innovative way,
- ensuring a higher quality of life (well-being), making the city more livable.

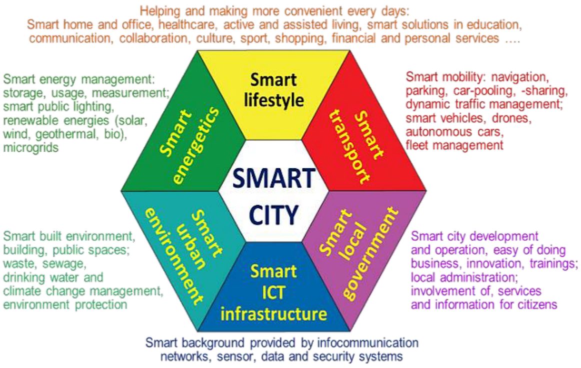

Fig. 9. Interpretation of Smart City key areas

The positive impact for the local community and the sustainability is expressed by the terms Smart City and Community (SCC) [31], and Smart Sustainable City (SSC), resp. Recommendations, standards are adopted for the transformation process [32][33] and the smart solutions [33]. The meta-architecture of the Smart Cities, based on [32][35] are shown on Figure 10, depicting the sandwiched ICT layers of sensors, infocommunication network, data center, digital platforms and smart applications between the urban environment and the urban life. Where the availability and affordability of the digital infrastructure (including some digital platforms) is guaranteed, it is considered a digital public utility [36].

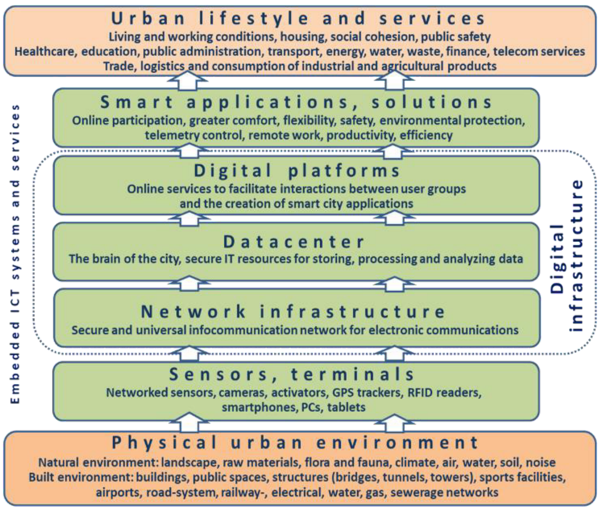

Fig. 10. The meta-architecture of Smart Cities

Diverse standardization, academic, industrial, consulting and urban organizations defined indicators to measure the performances of the cities on determined areas, e.g. [23][37][38]. Recently the most elaborated and recognized international indicator-system is the *United for Smart Sustainable Cities* (U4SSC), which is the initiation of the United Nations (UN) and coordinated by the International Telecommunication Union (ITU), and aims to provide guidance to cities in increasing smartness and sustainability [39][40]. The U4SSC has 91 key performance indicators (KPIs) in economic, environment and society dimensions (Figure 11), which are based on the ITU recommendation for evaluating the contribution of the use of ICT in making cities smarter [41], and the Sustainable Development Goals adopted by UN[42].

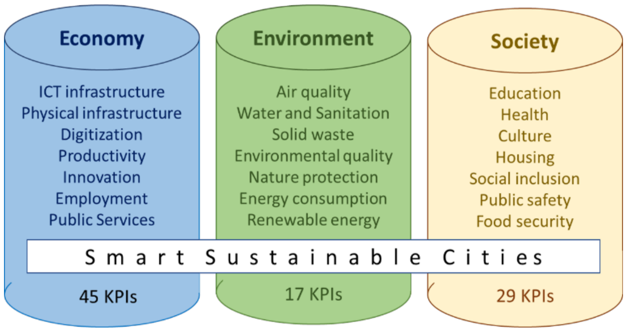

Fig. 11. The U4SSC indicator-system

Smart Factories are responses to the challenges of industrial production, building on the declining cost of sensors and actuators, the proliferation of the Industrial IoT (IIoT) and Cyber-Physical Production Systems (CPPS), the innovations in AI, AR/VR and robotics, as well as the secure information transmission provided by 5G. Business units located even at significant geographical distances from each other operate as an interconnected network, and all layers within the organization are interconnected from the manufacture to sales (horizontal and vertical integrations). The creation of a digital twin for manufacturing processes is yielding breakthroughs in many areas. Smart industrial systems are launching the fourth industrial revolution (Industry 4.0) [27][43]. Figure 12 depicts the three-dimensional Reference Architecture Model for Industry 4.0 (RAMI4.0), which was developed to support Industry 4.0 initiatives and gained broad acceptance by representing the different aspects and interactions [44][45][46]. At the same time, Industry 5.0 concepts are already pointing toward a sustainable, human-centric and resilient industry [47] .

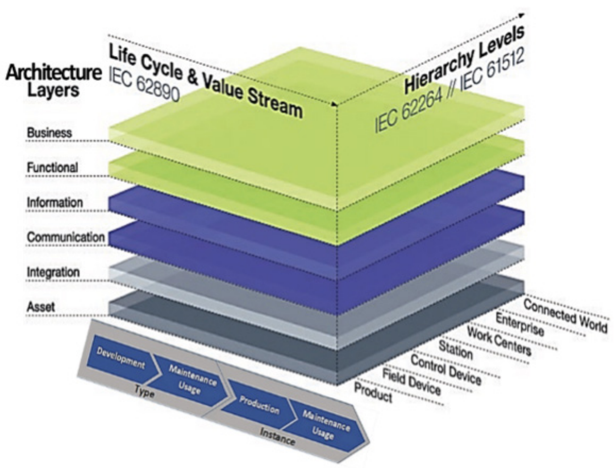

Fig. 12. Reference Architecture Model Industry 4.0

Smart Farms are emerging in agriculture and food industry [48]. Smart solutions appear, spread and combine for robotization, automation of operations, data-based, precision (location-specific) operations; there are self-driving tractors, drones; there are smart solutions for sowing, irrigation, fertilization, harvesting etc., mainly driven by the use of AI.

VI. Conclusion

The five evolutionary phases of the digitization process are presented, from the digitization of communication functions to the Smart Ecosystems. The digital convergence of communications, informatics and media technology, the concept of cognitive infocommunications, the extension of networking (namely the IoT), the immersive technologies (augmented and virtual reality) and the artificial intelligence have relevant role in the shaping of the concept of the Internet of Digital & Cognitive Realities and the Smart Ecosystems as Smart Cities, Smart Factories and others.

It is a natural evolutionary process due to the interaction of the technological evolution and the social demands, that the original concept of the Internet is expanding, involving the relevant results of the technological evolution, and becomes more and more universal. It happened in the case of the Internet of Things, and probably now with the Internet of Digital & Cognitive Realities. The next step is in question.

While digital convergence and networking have been the main drivers of Digital Ecosystems (networked society), Smart Ecosystems are already the products of the next, data-driven phase of digitization (knowledge society).

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Definition, Background and Research Perspectives Behind ‘Cognitive Aspects of Virtual Reality’ (cVR)

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Abstract—**In this paper, a definition outlining the scope and goals of the field of Cognitive Aspects of Virtual Reality (cVR) is provided. Leading up to and alongside the definition, the paper includes a discussion on the background behind cVR – with a special focus on new human-AI capablities driven by cognitive, psychological, social and technological factors. Finally, the paper provides an outline of related research fields that can act as synergies in relation to cVR, while at the same time formulates questions and hypotheses that may drive future research in cVR.**

Index Terms—**virtual reality; mixed reality, augmented reality, cognitive infocommunications; metaverse, cognitive aspects of virtual reality**

I. Introduction

Technological development in the past decade has led to the emergence of a variety of new applications in computer graphics that increasingly merge physical reality with the digital realm in the context of interactive 3D spaces. Such applications are often referred to as virtual reality (VR), augmented reality (AR), mixed reality (MR) or – in an overarching sense – as extended reality (XR) applications. In this paper, we often use ‘virtual reality’ (VR) as a general term for all of the above, for reasons explained in [1].

In a VR application, the user’s digital environment is often considerably enhanced and may also be augmented with digital representations of users (avatars), objects, events and processes (digital twins and simulations). Recently, with increased interest in the “*Web 3.0*” concept, a new kind of *Metaverse* is also envisaged which can naturally complement VR frameworks to create seamless interactions between the physical and digital world in a way that is not only spatial but also de-centralized and can also have strong social implications [2]. As the border between real and virtual becomes increasingly fuzzy, and as platforms emerge that are perhaps more de-centralized / participatory, a new level of human-ICT collaboration will become possible which of course integrates the existing digital 2D world, but also supersedes it in important ways. All of this in turn extends the capabilities of humans and ICT for further co-evolution.

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Even without Web 3.0 and the Metaverse, VR technologies are in and of themselves drivers of key changes in human-ICT co-evolution. Big Tech companies like Apple, Google, Microsoft, Facebook, Samsung and others have invested large amounts into these technologies, as a result of which VR has become a 12 Bn USD industry in 2020, a number that is projected to grow to over 72 Bn USD by 2024 [3]. There are in fact compelling reasons behind this growth. In much the same way that character-based user interfaces (e.g. MS DOS) were superseded in the late 1980s - early 1990s by graphical user interfaces (e.g. Lisa, developed by Apple in 1983, and later the Windows and Mac OS platforms), so too can it be expected that spatial content will become increasingly more prevalent and eventually supersede (but nevertheless integrate) 2D layouts. In parallel, as the relative benefits in terms of user effectiveness became clear following the transition from character-based to 2D GUI-based interactions, it can be expected that even greater relative benefits will be identified as a result the transition from 2D to 3D, as highlighted by a number of studies in recent years [4]–[7].

Although the pioneers of VR immediately recognized the technology as a foundation for a new infocommunications platform [8], it is still often considered as primarily being suited to applications in gaming and entertainment, and in the professional domains to simulation and training. During the past decade, we have seen gradual changes in this regard as well, as VR has become poised to enter the areas of basic and higher education [9]–[11], healthcare [12]–[15], engineering and many other professional industries [16]–[20]. With further increased support by AI methods, VR now emerges as a platform in which human capabilities are not only extended but also qualitatively augmented. In parallel, developments in miniaturized sensor and actuator technologies are leading to a further merging between VR and the digital twin concept, as well as more generally with portable and location-aware informatics devices. Humans, AI and digital twins, then, are emerging as a new ‘cognitive triad’ (see later) in VR; and as a platform that can integrate all of these trends, VR is changing the way in which information is accessed and understood by humans, leading to an increase in the effectiveness, productivity and safety of digital processes and knowledge transfer.

The field of “***Cognitive Aspects of VR***” is strongly motivated by a holistic perspective on “reality plus capability”

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technologies which can be expected to take the cognitive triad to the next level of the "spatial cognitive cloud". The increased data hunger of VR systems, the ability to process and interpret large amounts of data via AI solutions, the need to be able to monitor and control physical processes as well as the need for effective mitigation of information overload on the human side all point to this transition, which in turn can be expected to have an effect on human pyschological, social and economic structures.

II. Virtual Reality from a CogInfoCom Perspective

In this section, the background and possible future of VR is considered from the perspective of cognitive infocommunications – a nascent scientific field that focuses on synergies between modern infocommunications (which is itself a result of a convergence process between media, communications and informatics) and the cognitive sciences [21], [22].

A. VR as an infocommunications system

One key aspect of VR is that it expands both spatial and temporal perspectives, as well as enhances the way in which humans share, understand and organize information.

1) Spatial and temporal perspective: From this perspective, the role of VR as a radically new medium of communication that transcends space and time has been acknowledged for a long time. According to Jaron Lanier, who is widely credited for coining the term 'virtual reality', VR is especially unique in that it can lead to a way of thinking that supersedes even the conceptual level [8], given that an object represented in such a framework has the capacity to become an object in and of itself, rather than a representation of something else – in other words, the need for a mental transformation from reference to referent is removed. Further, from Lanier's perspective, VR is an environment where users can achieve new forms of self-expression in a collaborative way regardless of space and in a temporally asynchronous way.

Regardless of whether or not this vision eventually becomes actualized, VR holds the capacity to enable users to jump between past and future (imagined or prognosticated) spatial configurations regardless of their current physical location. Further, it can enable different scales of space and time to be interacted with simultaneously, in a spatio-temporal setting with its own somewhat modified logic (which nevertheless reflects the logic of physical reality). As a result, it can pave the way to the emergence of a new spatial way of thinking (spatial cognition) that is no longer tethered to the purely physical.

2) Information organization perspective: At the same time, with the emergence of specific VR platforms for the organization and sharing of web-based documents in a spatial context, perhaps a more recent realization is that the potential behind VR to radically improve the way humans organize information is no less groundbreaking. From this perspective, higher-level considerations both from informatics and psychology become strongly relevant, including, among others, how information can best be represented via spatial relationships, or how human capabilities for comprehension, retention etc. can be modeled in a spatial framework.

Specifically, it has been shown in numerous studies that more information can be shared and acted on in collaborative ways at a lower cognitive cost when 3D spaces are used as opposed to 2D representations, such that the semantic, spatial and / or temporal relationships among the content are reflected in their relative size and position in 3D [4], [5], [23]–[25].

As a result, VR represents a major step forward in the transition from command-based interactions to dyanamic interfaces based on affordances in keeping with human intuitions highlighted in [26]. In a strong sense, VR can be considered as an infocommunication tool that brings users an improved effectiveness, efficiency in parallel with an improved overall experience. It incorporates the capacity to share and collaboratively utilize large amounts of information, organized based on their relative importance, relative position within a workflow or in terms of other inter-dependencies in a way that transcends both space and time. At the same time, spatial interfaces in general can be more 'life-like' and hence more comfortable to users, who can now use their digital tools to understand and manipulate reality at multiple levels of space and time.

B. VR as a CogInfoCom platform

In the mid-term to long-term, VR can be expected to further merge together with sensor technologies and artificial intelligence, thereby becoming not only an infocommunication platform, but a platform that is more aptly described as a cognitive infocommunication (CogInfoCom) platform.

As described in [5], VR already incorporates the capacity to communicate with users along several new dimensions compared to more traditional platforms, thereby making better use of and in turn supporting human mental models that are grounded in space and time. However, complemented by sensor technologies (IoT) and AI, extended reality technologies in general are poised to integrate all corners of our daily lives, including more 'traditional' IT tools (documents, media, 2D interfaces), the physical 3D world (whether real, imagined or simulated), the user's mental reality (i.e. how information is organized, what content is relevant to which location at what time in the user's mind), and the influence of the user's decisions (real or hypothetical) on all of the above. With AI, such platforms can also become increasingly autonomous, thereby making decisions such as:

- what content to present to users in what location and at what time
- what concepts to use to help users search the content relevant to them, even at a higher, content-group level that addresses complete spatial layouts
- what paths to provide (in terms of sequences of locations and viewpoint orientations) to enable users to traverse through the displayed information in a sequential manner
- how to support higher-level human cognitive capabilities, e.g. memory, assocation, learning, recall, problem solving, collaborative effectiveness

It is important to emphasize that decisions made by such an autonomous system will likely be made based on the user's

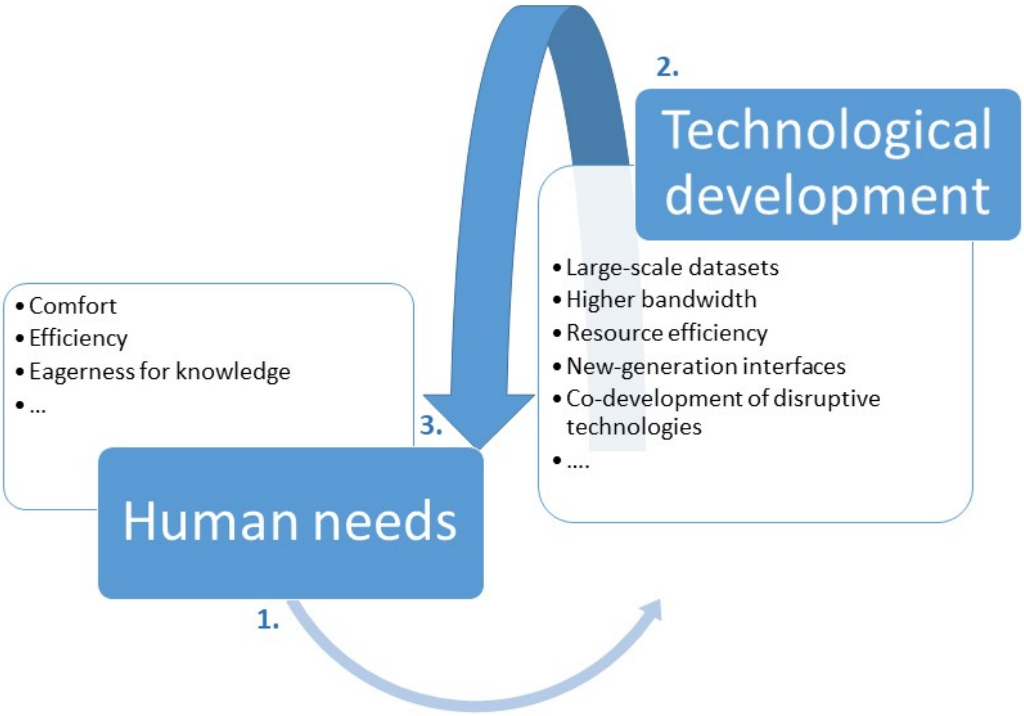

Fig. 1. Closed-loop cycle of evolving human needs that simultaneously drive and are shaped by technological development.

own behaviors (movement in the space, content consumption patterns, knowledge and capability metrics – which can be obtained through gamified situations [27], [28] – and more). As a result, a kind of symbiotic relationship can emerge between the human user and the AI supported ICT platform, with emergent behaviors that would be inconceivable without the involvement of both.

At the same time, the development of such autonomous AI-supported systems has a flip side in the sense that in order to perform well, such systems have the implicit goal of learning to "categorize" (predict) human thinking and behavior as closely as possible. One way to achieve this is to influence users' thinking patterns such that they fall into only a few well-defined categories. Some researchers argue that this is just the mechanism behind e.g. tribalism on social media platforms, or the emergence of just a few product categories that sell the best on e-commerce platforms – a result created by effective learning systems that usually have the goal of maximizing a single metric such as user engagement in terms of time spent on a given platform [29], [30]. Developing methods and solutions that turn the huge promise behind AI-supported spatial ICT into a reality while also credibly addressing such concerns is a key point of motivation behind cVR.

III. Definition of Cognitive Aspects of Virtual Reality and Synergies With Related Fields

Based on the above considerations, we propose the following definition for Cognitive Aspects of Virtual Reality (cVR):

Cognitive Aspects of Virtual Reality (cVR) *investigates the next phases of IT evolution characterized by a transition from digital environments based on 2D graphical user interfaces (e.g. windows, images, 2D widgets) to 3D spaces which represent a higher-level integration of VR/AR/MR systems, human spatial cognition, the 2D digital world (i.e. Web 2.0, Web 3.0) and artificial intelligence (AI). A primary focus of cVR is how this transition simultaneously makes use of and augments human capabilities, including psychological, cognitive and social capabilities – especially capabilities linked to a deeper understanding of geometric, temporal and semantic relationships. By extension, cVR further investigates the effects of these changes in human and AI capabilities with respect to a variety of sectors including education, commerce, healthcare, industrial production and others.*

In the context of prior research and other fields, cVR can both gain inspiration from and contribute results to the following partially overlapping / partially unique fields:

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A. cVR and Cognitive Infocommunications

Cognitive infocommunications (CogInfoCom) is an interdisciplinary research field that facilitates new syngergies between infocommunications and the cognitive sciences. One of the primary goals of CogInfoCom is to help the effective interaction between humans and computers and expand human cognitive capabilities with the help of infocommunications devices. Furthermore, it aims to provide a systematic view on the co-evolution of infocommunication devices, and cognitive processes [21], [22].

According to McLellan, virtual reality is a cognitive tool, as this technology was devised to enable people to deal with information more easily [31]. As outlined in section II-A, several recent results confirm and expand on this view. Importantly, it is a view that coincides with the aims of CogInfoCom – to extend and enhance the human cognitive capabilities – but does so in a specific framework of spatial technologies. In this sense, cVR and CogInfoCom are closely related.

B. cVR and Artificial Intelligence

Since around 2010, the field of Artificial Intelligence (AI) has seen a major breakthrough with the emergence of (deep) neural networks (DNNs) as an efficient and highly effective solution to many difficult problems. In the past decade, many classical approaches, including reinforcement learning [32] and even symbolic reasoning [33] have been cross-pollinated by advances in DNNs, leading to a true renaissance in AI research.

New approaches in cVR clearly have much inspiration to draw from modern AI methods, as many of the key problems behind cVR can be traced back to the challenge of modeling human cognitive capabilities using the only source of information available: the patterns based on which users interact with the given virtual reality. Examples of capabilities that may be relevant, in particular, within a spatial environment include:

- Capabilities for mentally organizing and navigating a large variety of information sources which may appear simultaneously in a single digital 3D environment (in much the same way as someone may have 50 tabs open in their web browser, a VR space could display 50 'in-game' browser windows at the click of a button [5]) – a challenge which evokes the term ***big big data***, which has to do with the analysis of simultaneous user interactions with an exponentially growing number of information sources
- Capabilities for influencing users' attention to, as well as retention and recall of information within VR – all of which are connected to the intelligent generation of environments, content layouts and also to the semi-supervised semantic modeling of content that users engage with [5]
- Capabilities for spatial navigation and for controlling avatar behaviors – which brings to the forefront the question of how humans can connect with an already deployed AI that transforms in puts to these modalities (a possibility that may emerge from the homuncular flexibility hypothesis, see e.g. [34], [35])

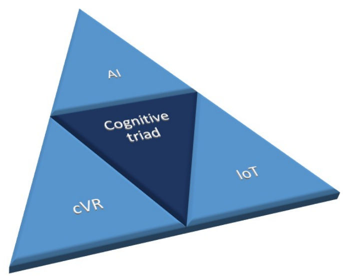

Fig. 2. Graphic depiction of the cognitive triad which represents a meeting point between humans, digital twins and AI.

- Capabilities for thinking based on spatial movements and spatial metaphors – a capability that is a core foundation behind human thinking [36]–[38]. Here, we posit the existence of what we refer to as an ***invisible VR*** – a virtual reality that already exists embedded in human mental models. The goal is to be able to map this invisible VR onto the visible VR that users interact with.

C. cVR and Internet of Things

As described in [1], the field of Internet of Things (IoT) represents a vision that integrates distributed computation (based on sensors, actuators, wearables and even digital twins) with intelligent connections. This vision brings the (dynamic) state of the physical world into direct connection with the digital world, and has quickly led to the emergence of further "Internet-of-X" fields including Internet of Everything, Internet of Nano Things, Internet of Mobile Things and more [39]–[41].

From the cVR perspective, it is important to note that the above fields are mostly technology (network) oriented, and therefore none of them address questions that have to do with the presentation / representation layer of the relevant applications. Further cognitive aspects, including users' capabilities towards understanding and acting upon the relevant data are also largely disregarded, as such questions lie outside of the technological aspects of efficiently connecting a large number of devices and routing data between them. Nevertheless, these are important aspects that can often be well addressed in the context of 3D spatial interfaces. At the meeting point of cVR, IoT and AI, a new kind of co-evolution involving humans, digital twins (IoT) and AI can emerge, which we refer to as the ***cognitive triad***.

D. cVR and Digital Reality / Internet of Digital Reality

According to Baranyi, Wersényi, Csapó and Budai [1], [42], humanity has reached an inflection point in its social and technological evolution, characterized by a human-ICT co-evolution and entanglement that could lead to a qualitatively new kind of reality. This is referred to as the digital reality:

"A Digital Reality (DR) is a high-level integration of virtual reality (including augmented reality, virtual and digital simulations, and twins), artificial intelligence, and 2D digital environments which creates a highly contextual reality for humans in which previously disparate realms of human experience are brought together. DR encompasses not only industrial applications but also helps increase productivity in all corners of life (both physical and digital), thereby enabling the development of new social entities and structures, such as 3D digital universities, 3D businesses, 3D governance, 3D web-based digital entertainment, 3D collaborative sites, and marketplaces."

The authors highlighted that digital reality is not equal to "all digital solutions", but is instead an integration of the different digital solutions such that human immersion and contextuality are key [1], [42].

cVR has a lot to offer when it comes to implementing Digital Reality, as spatial interactions are a key component of digital reality, and also because spatial and temporal contextualization are common to many cVR applications. At the same time, these fields have partially separate concerns as cVR places more emphasis on understanding the cognitive capabilities of users and ICT platforms in the context of a 3D interface, whereas Digital Reality has a more technical outlook on bringing together disparate realms of human reality.

IV. Conclusions

At the heart of the field of Cognitive Aspects of Virtual Reality (cVR) is how human cognitive capabilities can be both extended and augmented using a combination of technologies in a 3D spatial context. In this paper, a definition of cVR was proposed and its motivation and background was discussed from numerous perspectives. Based on this discussion, our hypothesis is that virtual realities tailored based on human-ICT cognitive aspects can result in simulated environments that are life-like to the point where physical and online activities can evolve into a blended experience.

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Virtual Teamwork in Gamified 3D Environment

Ferenc Erdős, Richárd Németh and Bayboboeva Firuza

***Abstract*—Virtual teamwork has spread strongly in various fields in recent times. COVID lockdown measures radically boosted the use of distance-independent remote collaboration methods. Although there are many modern virtual 3D spaces available for teamwork today, they lack additional motivational factors other than the visual 3d experience. Based on this, we tried to research the possible benefits of using gamification technics in 3D virtual collaboration environments to increase virtual team members' motivation. This article attempts to explore and highlight the possibilities of this area, and propose a model framework for implementation of gamified elements in 3D virtual teamwork environments.**

***Index Terms*—3D virtual collaboration, gamification, motivational factors, virtual teamwork**

I. Introduction, Basic Concepts and Objective

Virtual teams have become commonplace in everyday work over the past 20-30 years. According to the earliest definition, virtual teams are typically characterized as “groups of geographically and/or organizationally dispersed coworkers that are assembled using a combination of telecommunications and information technologies to accomplish a variety of critical tasks” [1].

Even if traditional phone discussions or e-mails can be the base of virtual teamwork, the info-communication foundation of modern collaborations is built on a 3D space platform and eventually with virtual reality extensions. These cutting-edge forms of teamwork need advanced info-communication solutions.

Several pieces of research [2] [3] [4] [5] [6] [7] investigated the theoretical background and effects of 3D Collaborative Virtual Environments (3D CVE) on teamwork performance.

Despite the improvements of new 3D collaborative technologies, virtual team members frequently feel the user experience demanding [8] and the lack of work motivation in virtual environments. With the use of different gamification techniques, we propose a gamified 3D CVE to increase the user experience and motivation.

The proposed objective fits the areas of Internet of Digital Reality (IoD), which is a set of several technologies that allow digital realities to be managed, transmitted and harmonized in various networked surroundings, focusing on a higher degree of user accessibility, immersiveness and experience with the help of virtual reality (VR) and artificial intelligence (AI)[10]. This enables the creation of a 3D virtual collaboration-based, perfectly customizable, almost futuristic type of working environment, extending the known limits of virtual space and teamwork while taking benefit of the meeting of the above mentioned technologies.

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II. Concept of Gamification

Most people love to play. Playing games during learning, of course, comes from pedagogy, but like so many other educational techniques initially used by children, it has proven to be extremely effective in the case of adults and works well in a corporate environment. As de Oliveira et al. stated, games were used as simulations to smooth disputes without wasting lives and resources, and also were used as an analysis tool. With the advent of video games, the role and significance of games has increased tremendously [12]. The system specially developed for this purpose is called gamification. In the past 15-20 years, thanks to the development of technology and social media sites, there was a considerable increase in attention toward this concept [13].

Gamification can be defined as the application of game elements in a non-ludic context [9], which can help team members to have better performance and supports an improved behavior. This internal type of gamification concentrates on the internal stakeholders of the company. It is not a negligible aspect that, as in real life, participants have to make efforts to be effective, whether it is about problem-solving, community interaction or achieving an objective. In this way, development, victory and improvement of position can be made even more tangible, and therefore can actually appear as a motivating factor, in addition to strengthening the spirit of competition or cooperation skills. The creative use of gamification helps employees in their learning process, in understanding tasks and in seeing the connections between different phases of work. The more we actively rehearse information, the easier it is stored in long-term memory [32] - the experience of learning in a 3D environment is quite unique, making it much more likely to transfer information from short-term to long-term memory.

III. Motivational Factors and Tools

Researchers usually distinguish between three basic types of game mechanics and game design that affect motivation: immersion-, achievement-, and social interaction-related features. “Immersion-related features primarily attempt to immerse the player in self-directed and challenging games, including game mechanics such as avatars, storytelling, and role-playing mechanics. Achievement-related features are principally intended to provide positive feedback to players;

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they may incorporate game mechanics, including symbols, challenges, missions, goals, or leaderboards. Finally, social interaction-related features attempt to use game mechanics to empower users' social interactions" [14].

A study carried out by the World Government Summit in cooperation with Oxford Analytica classified the elements of gamification into three main groups: personal, mechanical and emotional factors [15], displayed in Fig. 1.

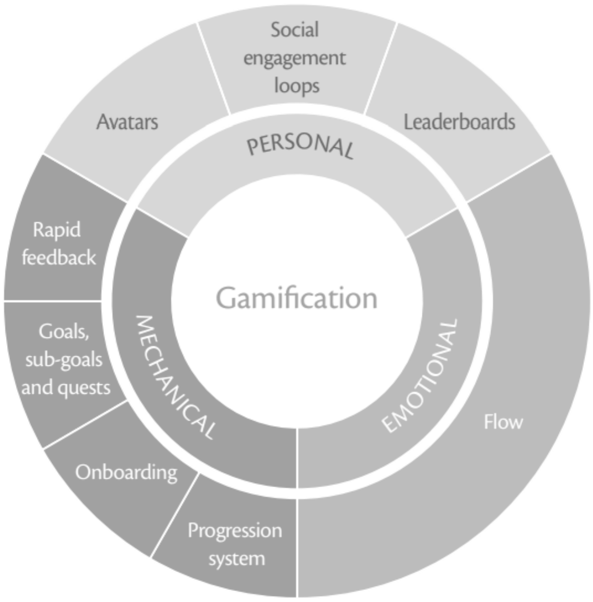

Fig. 1. Personal, mechanical and emotional elements of gamification

Personal elements of gamification are avatars, social engagement loops and leaderboards, the emotional side is characterized by the concept of flow, and mechanical elements include rapid feedback, goals and subgoals system, the onboarding process and progression. In developing environments and tasks based on gamification, competition and storytelling are also key elements – gamification users can earn points for certain actions, such as commenting on each other's ideas, so they compete [13].

In 2019, TalentLMS carried out a survey research project in order to collect the experiences of employees in workplaces where gamification was initiated in order to make workers more satisfied and production more effective. The results are more than thought-provoking. According to the survey, employees claimed that they were more productive and happier because of the positive effects of gamification [16]. As an outcome of the research, the authors collected the top five most significant gamification-like tools, which are rewards, badges, points, leaderboards and levels, respectively. Overall, it can be said that this internal type of gamification appears as a kind of factor influencing behavior and perception at workplaces, while further strengthens the experience of belonging to a community.

Teamwork also can be a motivational factor as partners and teammates can encourage and motivate each other, and collective responsibility is a driving force of cooperation.

IV. Gamification in 3D Virtual Environments

In current years, internal gamification software solutions in enterprise level have been potentially used for the formation and motivation of work teams. From this point of view, 3D CVE implementation with gamification elements can be an innovative and effective solution that helps to mitigate some negative effects of pure virtual collaboration.

Some related works have been already published in which virtual collaborative environments with gamification add-ons for teams have been researched. Wendel et al. [11] developed a virtual space in Minecraft with a serious game, that aims to enhance the soft skills in a team, such as communication, collaboration, motivation and teamwork. Bozanta et al. [19] proposed to apply serious games in a multi-user virtual environment as an efficient instrument to increase the unity, responsibility, communication, and collaboration of team members. The research results showed that the gamified user interface affects the communication, collaboration, and performance of the whole team significantly in the virtual 3D space.

Nowadays, the main goal is to smuggle immersive technologies into the workplace, not only in terms of learning and trainings, but also in terms of the work process. "Microsoft, Facebook and Samsung have already introduced a combination of software and hardware based on VR, AR, and MR. Facebook's Oculus for Business and Gear VR by Samsung are prime examples of such innovations that promise efficient, cost-effective and interactive learning through virtual simulations and a rich visual sensory experience" [17].

The importance of working in a virtual environment has been greatly increased by pandemic closures in the private sector because of the COVID–19 started from China in 2020, and the home office institution came to the fore in most workplaces. People were less and less able to keep in touch with each other physically, and the emphasis shifted from personal contact to online messengers, phone and video calls [24]. This, of course, had a destructive effect not only on social relations but also on teamwork and collaboration.

V. Teamwork with Avatars in the Metaverse

Virtual reality linked to 3D visualization and its diverse application prospects can be identified as one of the most significant topics of recent cognitive infocommunication research projects [21]. With the use of various display types, sound systems, and sensors, these systems may provide users an extremely realistic experience. The use of the currently known form of gamification, which is most typical for websites and social media, combined with the possibility of realistic representation provided by 3D space, also explores new dimensions in the fields of education, social interactions and working methods.

Obviously, nowadays social media sites and networks like Facebook belong to our everyday life, they form our thinking and interpersonal connections, influence the way we communicate, and they are also the platforms of exchanging information [25]. And the future of social media platforms will be three-dimensional for sure. Facebook has also changed its name to “Meta”, indicating that they want to bring the metaverse to life. Metaverse is defined as an internet-based 3D virtual reality world where individuals engage with each other and with software agents as avatars [20].

Throughout history, our lives were constrained by the laws of physical world and influenced by our senses. VR rewrites these rules. It allows us to digitize our experiences and teleport our perceptions to a computer-generated world where reality is constrained by our imagination only [29]. In our view, that day is drawing near when virtual avatars will open virtual files in a three-dimensional/virtual world, will show real processes on virtual boards, while the worker is sitting at home on the couch, with a VR headset and other devices creating lifelike reality. It will give us the ability to work independently of distance, in a workplace where we don’t have to go in, we don’t have to rent an office, we don’t have to be afraid of infections. We could work in a comfortable family environment at home, while the worker’s health is measured by sensors. It does not seem impossible that this will be the job of the future.

However, the concept is not much different from home office, which has already revealed several negative effects. During this type of work, we also have to deal with the erosion of social relationships, loneliness and depression [23]. Gamification can also help to solve these problems, as employees can really feel themselves at the workplace without sacrificing the benefits outlined above. We can take advantage of teamwork without anybody being around.

Nowadays more and more business communication platforms announce the development or go-live of their own metaverse. For instance, Microsoft Teams enables immersive collaboration with 3D virtual meeting spaces and avatars (see Fig. 2.) from 2022.

Fig 2. Microsoft Teams 3D virtual meeting space
Source: [30]

The common pillars of games and work are the need to meet the established rules, the necessity of immediate feedback and sub-goals. Gamification can implement these elements into a virtual world using the tools mentioned earlier. It is a great advantage that these rules can be changed arbitrarily within certain limits – the physical strength of a person no longer matters if the avatar he controls can lift huge weights (which is actually performed by a robot). You don't have to spend hours traveling every day, if the avatar can appear virtually immediately at another site, you don't have to draw on a whiteboard for minutes, you can paste the content you want with one click, and so on. The consequences can also be visualized immediately, you don't have to wait until an error report arrives and goes through the "chain of command" - the feedback system can also be automated and immediate.

A more advanced, almost realistic communication would be a great advantage over the communication methods of traditional, “distance” work. As Blštáková points out, communication within gaming situations is of paramount importance [18]. Our avatars can also be provided with additional information: name, position, current tasks, contact information, area of work - which may vary depending on our privileges. We can even give the user the freedom to customize their own look. It can also be applicable in the case of workgroups and teams. And here we are thinking not only of the team members but also of the characters in the computer world called NPCs (Non-Playable Character). These characters may have many different roles in a game, they can give assistance and guidance to players, they can tell a story to them, motivate them and so on [22]. Their “job” is to make the world more realistic with their mere presence. Communicating with them also contributes to a realistic experience.

In reality, communication is not just about speech, but also about body language, facial expressions and microexpressions - which are much easier and more realistic to display on an avatar's "face" in a three-dimensional, virtual environment. It would no longer take time to find the right person, we don’t need to be embarrassed asking questions – all the necessary information is visible on the avatar’s status panel. Many people are also inspired to see that their virtual abilities, rank, and classification within the group change positively – in fact, it is one of the main drivers of gamification.

It’s important to note that, in addition to feedbacks, the first impressions are also important (as an initial phase). This process is called onboarding, which “concerns the first interaction a player has with a game. Most games, particularly video games, have tutorials, which aim to guide players through the initial first few minutes of play” [15]. According to the above-mentioned study, we can distinguish four approaches of “freedom”: the freedom to fail (the user’s actions take place only in the simulation at first), the freedom to effort (we can test our abilities in different situations without consequences), the freedom to explore (without risk and harm we can experiment with new solutions and methods in a kind of "sandbox") and the freedom to assume different identities (we can try ourselves at any time in a new job or at a higher level of responsiveness). Our virtual selves can be used perfectly even in the learning phase – and the efficiency is not comparable to the tutorial videos and manuals used in the home office.

VI. Proposed Model For Development of Gamified 3D Virtual Teamwork Environments

Because of the fact that numerous factors can influence teamwork processes and they can strongly vary depending on the circumstances, achieving an optimal performance with a team is fairly difficult. However, a regular problem is that employees often lose their interest in the joint goals, which reduces their motivation to collaborate. In the following, we will try to propose a model for the development of gamified 3D spaces suitable for teamwork. We focus on a typical everyday situation, where independent teams compete to each other in order to achieve a better team performance.

Game components appear to be a potential tool for promoting teamwork. The design of game features for teamwork can be influenced by organizational psychology, where many conditions for excellent team performance have been suggested [26]. Interdependence and team cohesion, among other things, are cited in relation to team performance [27], therefore these variables are suitable beginning points for developing gamified components for 3D virtual teamwork.

Task cohesion (commitment to the goals and tasks of a team) and social cohesion are two types of team cohesion. The importance of interdependence relies on that team members help each other to a greater extent when tasks are more interdependent.

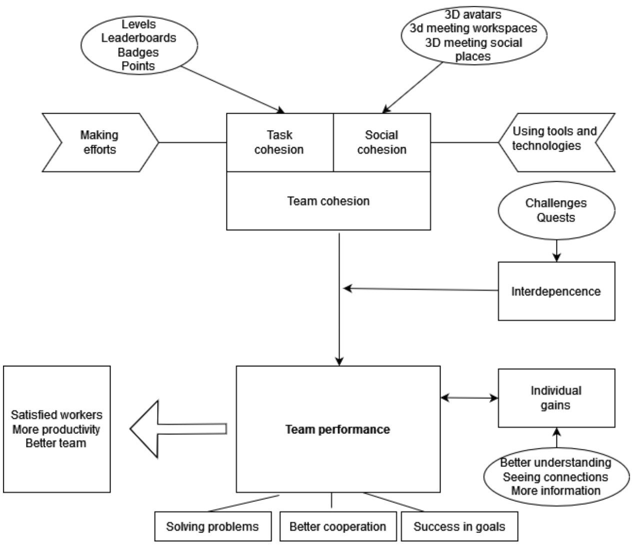

Fig 3. Proposed model for implementation of gamified elements in 3D virtual teamwork environments

The model on Fig 3. highlights the potential gamification elements that can be applied to a 3D environment to enhance team performance. While most of the common gamification elements (i.e. points, badges, levels and leaderboards) are able to strengthen task cohesion, 3D space specific elements (3D avatars, 3D spaces for work meetings and social events) can significantly support social cohesion.

Gamification can help the teamwork process by establishing explicit goals and guiding players toward competitive or cooperative behavior through game rules.

Users' motives are frequently emphasized as a key aspect in gamified environments. It would be difficult to develop an efficient gamified 3D platform if game components do not address elements that inspire team members. As a result, we propose a bottom-up approach in which employees' needs and desires are prioritized.

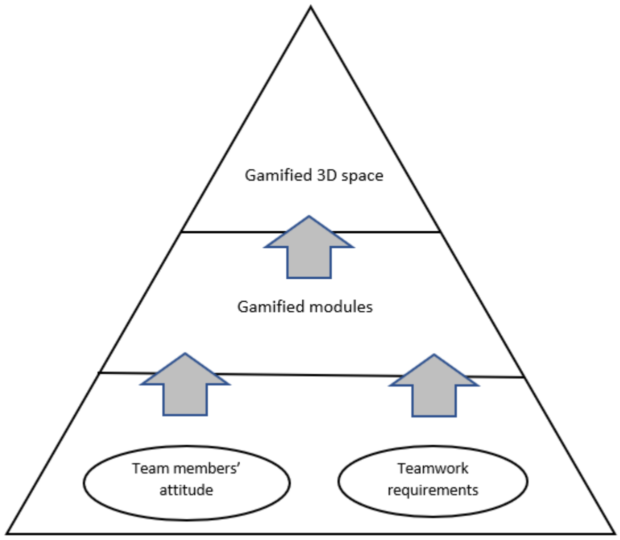

Fig 4. The bottom-up approach of gamified 3D virtual teamwork environment development

With the bottom-up approach, it is possible to develop a 3D virtual environment suited to the actual team's characteristics. The development of reusable low-level components can be the basis of a successful framework. Then these components need to be interconnected to constitute high-level constructs.

VII. Barriers of 3D Gamification

Of course, the three-dimensional representation of gamification is a novel experience, not only for home users but also in the world of work. Spectacular visualization can not only make progress in increasing user activity in the area of social interactions but can further strengthen addiction.

Despite the advantages described earlier and the potential of the technology, we can expect that the spread of the metaverse will not be smooth. This is the case with all new ideas: at first, there is strong resistance to the new, especially at workplaces. For most of society, the majority is quite conservative when it comes to compulsion. As we can see in many areas of digitization, there is significant resistance to the new, especially at the middle management level. According to some gamification experts, the management usually argues against gamification, because it could be a distraction and could reduce productivity [16]. The new generation is slowly making a difference, and the members of the older generation, who are adhering to traditional methods, are slowly being replaced by members of the Y and Z generations.

Lack of interest from the above can also be an obstacle – this is exactly what 3D virtual reality can change, aiming to make the virtual world even more realistic than the real one – only better! At the same time, it is important to strike the right balance, especially in relation to gamification mechanics. We need to be aware that people need to be motivated differently when they are in the same team. Leaderboards can be extremely successful in pushing some team members to improve their behavior. For other ream members opportunities to collaborate and empathize with other members would be more appealing [28].

As for the 3D visualization, the main reason for the previously poor performance was the excessive hardware requirements – the problem is on its way to be resolved, thanks to the hardware and software development. Lack of access to technology can also be a barrier, mainly due to the high cost of the equipment required. A recent survey showed that only 65% of urban households and 28% of rural households have computers and/or internet access [13]. Nevertheless, we can be sure that with its proliferation, VR-enabled devices will become cheaper. Based on the general definition of convergence, both gamification and virtual reality are exponentially accelerating technologies [29] – so we can reasonably expect rapid proliferation and rapid cost reductions.

VIII. Conclusions

As we have highlighted, gamified 3D virtual collaboration has a huge potential in virtual teamwork. In this article, we studied the possibilities of applying different gamification elements and techniques in 3D virtual collaboration. As there hasen't any related framework published yet, we provided a novel model for implementation of gamified elements in 3D virtual teamwork environments. We realized that virtual 3D space specific elements can significantly support the social cohesion effects of team members. Of course, this topic requires further quantitative and qualitative research to establish an effective gamified 3D collaboration space for teamwork.

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Musings on the Metaverse and on how the Internet of Digital Reality Encompasses Future Developments of the Internet

György Wersényi

Abstract—**Internet of Digital Reality (IoD) is a concept that encompasses various aspects of the next level of communication between digital cognitive entities. Extending the concept of IoT and IoE, IoD includes all kinds of entities interacting in virtual reality, focusing not only on the technology, physical and logical networks, but also on cognitive aspects and human factors. The Metaverse – as a key element of IoD – was introduced and has lately been re-vitalized as a kind of vision for the future of the Internet, especially focusing on social media, where users interact via their avatars in a fully immersive VR scenario. In this paper, I nevertheless argue that IoD is more than a "VR Facebook", and that although the Metaverse can offer a new kind of experience, it isn't free from drawbacks and valid criticisms.**

Index Terms—**Internet of Digital Reality, Future Internet, Facebook, Metaverse, Virtual Reality**

I. Introduction

A. What is the Metaverse

The Metaverse can be seen as the next level of the Internet with decentralized, persistent online 3D virtual environments [1]. Virtual spaces in the Metaverse will be mostly accessible not only through VR and AR headsets, but also via mobile devices and desktop computers as well. The Metaverse can be expected to have many use cases, however, currently it is more a vision and a future perspective than an existing platform due to technological limitations regarding access devices, sensors, actuators and computational capacity needed to interact with and "live" in such real-time virtual environments.

In 2008, Sivan tracked the term Metaverse back in history to as early as 1992 [2]. Its first use cases were collected in that work, such as Second Life, where human characters spent their time, played, worked and lived in a 3D environment focusing on social structures and business as well. There is still no consensus about the definition of the Metaverse. Song suggested that the components of virtual reality, mirror worlds, augmented reality, and life-logging would serve as the pillars of the Metaverse, and proposed a definition that included human behavior and user experience [3]. Mystakidis defined it as a post-reality universe, a persistent multiuser environment merging the physical world and digital virtuality solutions, mainly via AR and VR technology [4].

This paper reviews previous literature on the Metaverse and attempts to provide a refined definition and a structural gathering for this social and technological phenomenon. Furthermore, the main goal is to find its place among the various emerging fields beyond IoT, especially, where not only the technical development but human factors and cognitive aspects play a significant role. Finally, critical aspects and current technical and non-technical problems will be collected and highlighted to suggest directions of development. From the social aspect, the Metaverse can be seen as a "social good". The technology promises to weaken differences in gender, race, as well as mental and physical disabilities in the near future. On the other hand, masking real life properties of human users and hiding behind idealized avatars can result in problems and deepen existing real life problems. Therefore, science, research and development of such systems should strongly focus on human factors [5].

B. Facebook and Meta

In 2020 NVIDIA presented a 3D real-time simulation and collaboration platform called "Omniverse" as a next-generation alternative for the Internet. At Connect 2021 conference, Mark Zuckerberg introduced Facebook's vision of the Metaverse as the successor to the mobile Internet, and announced that his company would be renamed to Meta [6]. In Zuckerberg's vision, the interconnected digital spaces of a Metaverse would allow one to do things that would otherwise be impossible in the physical world (however this could be also true for various other things). Zuckerberg's Metaverse is also characterized by social presence, the feeling of being there with another person or other people, and can be expected to eventually encompass work, entertainment, and everything in between.

However, the main focus within Zuckerberg's Metaverse is nevertheless on social media, thus, it is a technology envisaged primarily for the enhancement of interaction among human users. Applications such as Horizon Home for the Oculus Quest platform, will be extended by Horizon Worlds and Workrooms for social interaction in the VR world. Horizon World has already gained 300,000 users by February 2022, having increased the number of users tenfold in 3 months (Figure 1). The platform is meant to be the successor of Facebook, a cartoon-like virtual environment inside which avatars can interact. In a way similar to Minecraft, users can build their own environment, and many "sub worlds" already exist.

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Fig. 1. Promoting Tweet of Horizon World

Fig. 2. Virtual meeting places in Teams 2022

Meta's AI Research Supercluster (RSC) computer system will serve to handle communication among tens of thousands of users, including sophisticated content filtering and moderation. Currently, the cluster uses 6800 graphic processors, and can complete machine vision tasks 20-times faster than the competitors. When completed, it will have 16,000 GPUs, one exabyte of memory, and will perform AI learning at 16 TByte/sec speed. VR support for Messenger has been launched already, and voice calls will be included with the system in the near future.

C. Beyond Meta

Gaming in virtual reality not only includes action games, but AR/VR Chess, Formula racing and other sport activities will be available. The idea is getting new traction through online gaming using virtual reality [7], i.e. the Oculus Quest 2 VR headsets are going to be extended by further sets of accessories, while Quest for Business is being developed for work scenarios [8]. Microsoft also announced new developments after Facebook's press release, raising attention to Minecraft as a Metaverse game. The company's other popular games called Halo and Flight Simulator can be seen as a ”2D Metaverse game” already that would be enhanced by 3D technology. Furthermore, Microsoft announced that users are able to portray themselves as a cartoon avatar in Teams with Microsoft Mesh (Figure 2).

Another development from Facebook, called Project Cambria (unofficially called Oculus Quest Pro) will be a high-end device at a higher price, packed with all the latest advanced technologies, including improved social presence, eye and face tracking, pancake optics, and more. Photo-realistic avatars and real-time, 3D reconstructions of real-world locations will be offered for VR (Figure 3) [9].

In the case of the Metaverse, it is important to stress that even if the spaces (including navigation, exploration techniques, graphics etc.) look like 3D games, the content is not necessarily (and in general will not be) determined and modified by a game developer company, but by the users. For example, both human users and legal entities like companies can buy land, properties, VR commodities, which can then be modified dynamically within the spaces. Pioneers of this vertical market include fashion companies (Gucci sold a digital replica purse for more money than the original real-world item), gambling, cryptocurrency exchange (CFD), and auction houses. In a recent interview, Zuckerberg himself has expressed his vision that users will spend as much money on their VR clothing as on their physical clothing [1].

D. Progress in the Metaverse

Moving from independent virtual worlds to an integrated network of 3D virtual worlds rests on progress in four areas: immersive realism, ubiquity of access and identity, interoperability, and scalability – areas that were defined and described already in 2013 [10]. Institutional and popular interest and ongoing improvements in hardware performance were mentioned as key factors for a functioning Metaverse, and they still have not been solved in the last decade.

A three-layer future architecture for the Metaverse has been suggested from a macro perspective, containing infrastructure, interaction, and ecosystem. The authors also presented a historical overview and discussed novelties of the Metaverse with a detailed timeline and table of specific attributes [5].

A related concept called the “Immersive Internet” has also been proposed as a gigantic, unified, persistent, and shared realm. It has since been recognized that emerging technologies such as mixed and augmented realities, 5G, Artificial Intelligence, HCI, Edge and Cloud computing, as well as IoT are a part of this concept [11].

At the same time, Seidel focuses more on the connection aspects of the Metaverse, calling it a “meta design space”. In this context, spaces are interconnected, created by “designers” and transitions between physical and virtual experiences are

[1]Zuckerberg on the Lex Fridman podcast, February 26, 2022: https://youtu.be/5zOHSysMmH0

Fig. 3. In Meta's Metaverse, people create avatars of themselves with specific facial expressions or skin colors. The Cambria headset is specifically designed and it will includes sensors that enable a user's avatar to make natural eye contact in real time.

especially important [12]. Designers are still human actors, although artificial entities can also evolve to designers in the future.

A description and prescription of the value chain of this market was also provided – a vision for the future powered by creators and built upon decentralization and grouped into seven layers as seen in Figure 4 [13]. The potential and risks of globally accessible 3D virtual spaces as part of the digital transformation of society and business was also recognized [14]–[16]. MetaSociety will emerge in MetaCities, where MetaEnterprises create a MetaEconomy – mapping of real world entities and business into the virtual space [17].

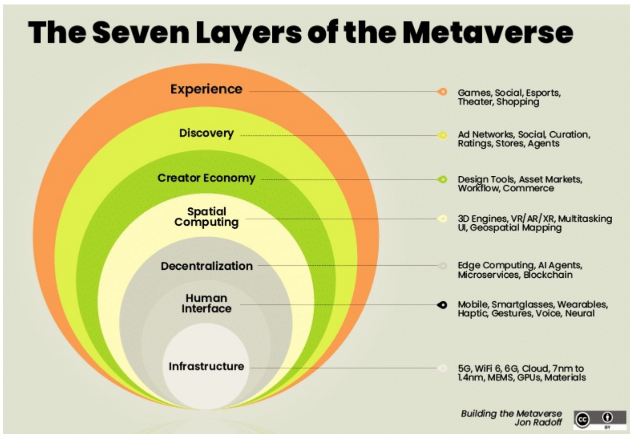

Fig. 4. Seven layers of the Metaverse [13]

E. Metabusinesses

Goldman Sachs has recently listed the most important companies relevant to the Metaverse, such as Meta (Facebook), Snap, Nvidia, Google and Roblox. Some of these companies are already present on the stock exchange [18]. They see Metaverse as the next generation Internet, also known as Web3.0. Web2.0 moved communication from the desktop to mobile devices and cloud services, Web3.0 will be the VR-based Internet using avatars. The basic technology should be Non-fungible Tokens (NFT) and blockchain. The goal is twofold: enhancing the physical world with values using AR and having open interfaces, standards and roles with an expected roll-out in ten years. At the beginning of the Internet era, users were in "read-only" mode, exploring static, rarely updated 2D webpages. Around 2005, a new paradigm arose, as websites went into "write" mode from the user's perspective: blogs, social media, videosharing sites created a platform for self-expression that we call Web2.0. Web3.0 will be extended by ownership and digital property rights, where digital documents and art can be valuable products, with the ability to differentiate between original and copies (see e.g., the Bored Ape Yachting Club cartoon monkeys, CryptoPunks NFT collections, see Figure 7). NFTs have introduced new possibilities and together with blockchain technologies they can serve as a basis for future business models in the Metaverse and various digital reality applications [19], [20].

In February, 2022 JP Morgan's Onyx blockchain division

Fig. 5. JP Morgan's virtual property in Decentraland

published a short report on the Metaverse and revealed that the company acquired a piece of virtual property in Decentraland (Figure 5).

Currently, business in Decentraland is based on cryptocurrency. The NFT market correlates with the cryptocurrency market, and pricing of the latter can help in understanding NFT pricing patterns [21]. However, there are many risks in cryptotrading with crime control being absent [22]. The easiest way for companies to enter the Metaverse is based on already existing customers, fans, or "followers" in the real-world, independent of whether the product is physical or virtual (e.g., a service). Influencers, who have become key players in the pop culture of the previous decade (the 2020s) and have a great influence on business models can attract people to these ecosystems and by reaching a critical mass of users, they can contribute to the mass acceptance new technologies. There is still no original application specifically developed for IoD (and for the Metaverse). Existing solutions are simply placed in a 3D environment without exploiting the possibilities of immersion. Furthermore, there are no metrics or measurement methods to certify the outcomes.

Whether these new technologies will be hyped-up playgrounds for the elite or will be used to create serious applications for the Web3.0 that are secure and decentralized will be revealed in the future.

II. Evolution from IoT to IoD

Internet of Things (IoT) describes the network of physical objects, things, that are embedded with sensors, software, and other technologies for the purpose of connecting and exchanging data with other devices and systems over the Internet [23], [24]. Things can be physical machines, or sensors that have a virtual counterpart (a virtual or digital twin). We associate IoT with a large number of machines that are connected, creating something "smart", usually being able to make some kind of simple decisions. It is also a collection of non-human users communicating on the Internet with some degree of freedom. With the introduction of higher-level decision making, machine learning, artificial intelligence etc., the concept of IoT can be extended in many ways [25], [26].

As a case in point, the **Internet of Everything (IoE)** includes people, data and processes within IoT based on smart, intelligent networked connections. Network intelligence is a key factor here, but human factors and non-technological issues are still neglected.

The concept of **Internet of Digital Reality (IoD)** was introduced for a better understanding of new possibilities behind the sharing of digital realities in networked settings [27], [28]. The term Digital Reality is not new, it has been used for different reasons and from different aspects [29], [30]. Technological developments in communication, management and human-computer interactions have led to quantitative and qualitative evolution in many ways. First of all, modalities for accessing and displaying information are being extended beyond 2D audio and video. 3D spaces, fully immersive environments using all modalities require not only new equipment, but the understanding of cognitive factors and users' behaviour. A virtual environment shared by human users, machines, AIs, digital twins etc. poses an enormous cognitive load, danger and possibilities (Figure 6). IoD deals with these problems from a principled scientific perspective. To highlight the importance of the cognitive aspects, the 1st international conference organized on IoD concluded to complement the term of IoD to be the Internet of Digital and Cognitive Realities.

The most relevant aspect of IoD is that it creates a higher-level functional integration (network) of digital entities, 3D virtual environments, different technologies and information (data). Real-world counterparts of these entities may or may not exist. A digital (cognitive) entity can be seen as a 3D representation of a "homepage". Today, information can be accessed using text input/output, two-dimensional stills and/or motion picture visual information and sometimes using sounds.

Pillars of IoD have been listed as follows [27]:

- Cognitive entities interacting in the digital reality
- Information and data
- Underlying communication networks
- Artificial Intelligence
- Accessing hardware interfaces
- Cognitive infocommunications and human factors
- Safety
- Digital business and legal issues
- Digital Society

In a 3D VR scenario, information can be accessed in a more natural, intuitive way by moving and navigating in a 3D immersive space, replacing traditional I/O methods with gestures, haptics, 3D audio/video and speech communication. The role of the Metaverse here is to serve as an organized collection of 3D spaces which on the one hand serve as a foundation for decentralized digital economies, but which on the other hand can also contribute to the creation of new digital realities (provided that they participate in a high-level integration of capabilities towards a specific goal) [27], [28].

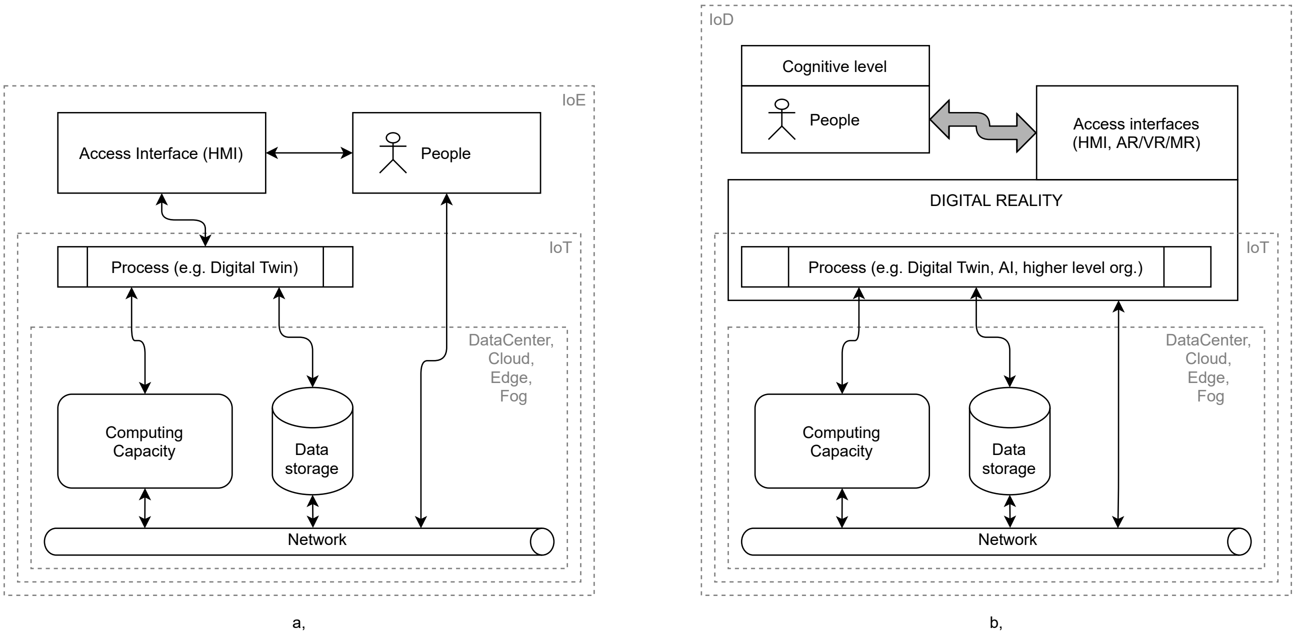

Fig. 6. Overview of the different philosophies of IoT, IoE and IoD

The Internet of Digital Reality in turn enables such realities to be shared and managed in networked scenarios.

A. IoD in the Popular Culture

In 1984, William Gibson's multiple award-winning science-fiction novel of the cyberpunk genre called Neuromancer hit the shelves. It introduced the global computer network in cyberspace, a virtual reality dataspace called the "matrix". In this future with the help of brain-VR/AR interfaces users can enter the grid-like 3D virtual environment inhabited by representations of real world entities. It can be explored and communication and information transfer is maintained under the supervision of various artificial intelligences. Later, the book was extended to a trilogy, followed by computer games with the same name on the C64 and Amiga platforms.

The concept of the Metaverse – and the name itself – first appeared in Neal Stephenson's Snow Crash story (1992) years later, where a pizza delivery boy acted as an undercover agent in the Metaverse. It is Stephenson's vision of how a virtual reality–based Internet might evolve in the near future, populated by user-controlled avatars, as well as system daemons. It appears to its users as an urban environment, developed along a single road that runs the entire circumference of a spherical planet. In 2021 HBO Max announced that they are developing a TV series from the novel.

Later, movies such as the Matrix Trilogy, Blade Runner, Johnny Mnemonic, Japanese Manga series (Akira) and RPG games (Final Fantasy, Cyberpunk 2020 and Cyberpunk 2077) made the genre even more popular. Post-industrial dystopian future settings, high-tech, cybernetics, advanced robotics, multinational corporations and virtual reality have been essential parts of the stories and artwork. Even the music industry gave rise to formations in the 80s (Kraftwerk, Psydoll, Sigue Sigue Sputnik) that combined electronic music, heavy riffs and retrofuturistic outfits. Digital fine arts and even architectural design were touched by the genre.

III. Metacritics

Along with renewed interest in the Metaverse, critics have also emerged, claiming that the Internet and related technologies are already a Metaverse in their own right, and that adding VR to this mixture is just another way to increase marketing efforts – an attempt by Facebook to catch up with Google, Amazon and Microsoft, while at the same time to counteract its decline in popularity among young people compared top platforms like TikTok, Minecraft and Roblox [31].

In parallel, more principled concerns have also been made public, including whether each player in big tech will create its own Metaverse, while trying to lock in users with specific hardware and software solutions. The question of whether decentralization can retain its original meaning in such an environment seems to be a valid one.

There are equally concerns about how the Metaverse can be regulated, e.g., how control over accessible content is to be managed. A correspondent of BBC News entered the Metaverse with a fake profile of a 13-year old girl using the Meta Quest VR helmet and had unrestricted access to adult content. Of course, this problem may be somewhat independent of the Metaverse, as access to any kind of web-based content raises similar challenges, although the fact that the Metaverse is expected to rely on decentralized solutions more than any networked technology before may be an indicator of renewed challenges in this area. Decentralized systems have the problem of responsibility that has to be addressed in order to gain trust.

A. The Pyramid Scheme

At the beginning of 2022, Zuckerberg presented the numbers of Meta about the 4th quarter and the total year of 2021. Number of users, profit and stock exchange rates were falling. The historical decline of stock value by 26 percent in one day resulted in a multi-billion dollar loss. Especially young people do not seem to be really inspired about Zuckerberg's Metaverse, and falling business expectations for the future are more important for stock exchange rates than visionary thinking. Other tech companies such as Spotify or Netflix also suffered losses.

On the other hand, the real estate business in other Metaverses (Sandbox, Decentraland, Somnium, Cryptovoxels) seem to be very popular. In 2021 more than 500 million dollars were spent on virtual real estate. Basically, there is no upper limit to the amount of money exchanged for digital landscapes, which prompted many business insideres to point to pyramid schemes. Even using NFTs for property rights is an idea that brings with itself more questions than answers, as there is no real value or central executive body behind them.

There is a connection between NFT and cryptocurrency sales, and both markets promise perspectives and risks [32], [33]. A systematic study about the opportunities and challenges of NFTs was given in [34]. Similarly, an overview covering 146 research papers on aspects of cryptocurrency trading was presented [35]. These considerations are more financial than technical ones, and they can be driving factors behind the developments for the Metaverse.

A pyramid scheme is an unsustainable business model, where top-level members recruit new members, who pay costs up the chain [36]. It is illegal in many countries and it is seen as fraud. Multi-Level Marketing (MLM) is almost the same, but usually involves some kind of goods and services to be sold, often virtual or no-value products. However, these are legal business practices [37]. The so called Ponzi schemes do not necessarily have a pyramid structure, but promise high returns by taking investment money from recruited newcomers who end up losing their money [38]. Virtual real estate investments following these schemes foreshadow a bubble waiting to burst. Even if there would be unlimited number of spaces and financial assets backing NFTs, the number of possible customers willing to pay are limited.

B. Technology behind Metaverse and IoD

Another issue behind the Metaverse and also perhaps behind IoD is that virtual and augmented reality technologies including audio, video and haptics modalities are not yet fully developed.

Decades ago, VR spaces and the underlying technologies were science fiction, and simply reflected how authors imagined the future. In the meantime, a parallel but synergic evolution of various technologies offer a new, combined reality

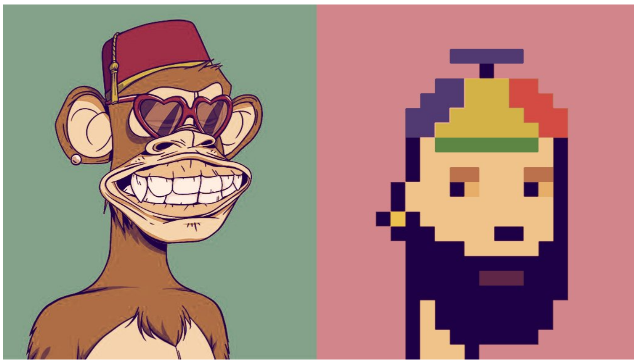

Fig. 7. A Bored Ape and a CryptoPunk: the most popular and largest Ethereum profile picture projects based on NFT.

or realities [39]–[42]. The question is whether concurrent solutions of metaverses will be compatible, massively scaled real-time in 3D and interoperable, i.e. whether the end result will be a single Metaverse, or locally managed independent solutions.

VR faces problems that are similar to those faced by 3D television some years ago: complicated equipment was needed for something that could be done in 2D easily and effectively (e.g., Minecraft's VR playing mode is the least played version). Use cases and applications have to deliver real improvements in user experience, safety, user friendliness etc. in order to put Metaverse and IoD applications on the shelves. Social impact, human factors became a significant role and IoD deals with these questions as well.

Research within IoD (and thus within Metaverses as well) is also focused at network and communication solutions. 5G and the upcoming 6G technologies (the Chinese company Oppo has already presented the first white book) will offer high bandwidth and low latency at relatively short spatial distances (some tens of meters).

IV. Research Areas and Future Agenda for Developments

The Metaverse - as part of IoD - has gained much research attention in recent times. A research agenda was also proposed about the Metaverse. In this, various computer-mediated virtual environments were created including social networks, video conferencing, virtual 3D worlds, AR and NFT games [11]. The authors defined the Metaverse as "*a virtual environment blending physical and digital, facilitated by the convergence between the Internet and Web technologies, and Extended Reality*", a duality between the real physical and the digital virtual world. However, the main focus is on the users' avatars and the way they can live a different (second) life in the digital reality. This might be a different approach than used by digital twins, where the similarity between the real thing and its digital twin should be great and model its functionality as good as possible.

A blockchain-driven Metaverse prototype of a university campus was designed, tested and discussed in [5]. The main focus here was on applications for social goods. The Metaverse's architecture was decomposed into three layers, namely infrastructure, interaction, and ecosystem, and a timeline of evolution was envisaged for future developments.

A. Internets of Whatever

The introduction of the Metaverse into the spotlight brings along with it associations with existing and new terms of "Internet of X" solutions. There is an endless possibility of creating such phrases. This highlights the need to extend the well-known terms of IoT and maybe IoE as well. Different areas beyond IoT are emerging, focusing on different aspects, fields of interests and trying to evolve to a stand-alone field of research. The Internet of Nano Things (IoNT), the Internet of Mission-Critical Things (IoMCT) and the Internet of Mobile Things (IoMT) show the need for further differentiation within IoT [43]. Medical experts have also proposed a definition of the Metaverse in Medicine as the Medical Internet of Things (MIoT) using AR and/or VR glasses [44].

The Internet of Skills defines a network based on connections between skills, actions and activities [45]. Especially the case of haptics as a modality using 5G networks and its capabilities (such as network slicing, QoS measurements) for healthcare applications is in focus. Here, not only "things" and "users" are connected, but capabilities, competences, information and know-how, with strong focus on usability, manipulations and interactions.

Unfortunately, the abbreviation IoS can be used for different things. Regarding audio applications, the term Internet of Audio Things (IoAT) and Internet of Musical Things (IoMusT) forming together the umbrella term Internet of Sounds (IoS), showing the need for extension of the IoT term in the world of sounds [46], [47]. The Internet of Musical Things is a research area consisting of the extension of IoT to the music domain. Interoperability represents a central issue within this domain, where heterogeneous objects dedicated to the production and/or reception of musical content are envisioned to communicate between each other [48]. The Internet of Sounds is a research area that is progressing at a steady pace, with several endeavors aimed at the academic, industrial, and artistic level. It stems from the intersection of the field of Sound and Music Computing with that of IoT [49].

To make things more complicated, IoS also denotes Internet of Senses, referring to connected sensors in order to interact with digital entities from the distance, using modalities different from auditory and visual [50]. All these suggest that the term IoT is exceeded, and there is a need for a higher level concept covering new areas that we call IoD (Figure 6).

V. Conclusions

The concept of the Metaverse was recently re-defined and introduced to the wider public by Zuckerberg. However, the term, and more importantly, the content and meaning of this term is not new. The Metaverse seems to represent an evolutionary step towards the future of the Internet, where users are immersed in a 3D virtual environment within work, entertainment, gaming, social media and other use case scenarios, and can trade commodities within these use cases in a decentralized way. Though it is the source of widespread excitement, the Metaverse has also drawn critics, who claim that it is just another way to generate profits and does not represent substantial novelties. Who is correct remains to be seen, but research agendas, fields of interests were already introduced showing the need to extend the Internet of Things concept. In this context, it is important to note that cognitive digital entities will be the future actors of the Internet, including human users, things, skills, AIs, using new hardware and software developments, networks, I/O devices and modalities. Given that the Internet of Digital Reality (IoD) covers all these with a strong focus on cognitive infocommunications, human factors and related sciences, it seems to be a valid argument that IoD is a more general concept in which Metaverses can play a key role.

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The Concept of BENIP – Built Environment Information Platform

Balázs Horváth, János Szép, and Attila Borsos

Abstract—**The built environment and its components require a continuous and uninterrupted flow of information between its various players. In this paper a conceptual framework is proposed describing the role of these players as well as the nature of the links between them. The authors introduce a new term, a conceptual framework which can be used as a platform called BENIP (Built ENvironment Information Platform).**

Index Terms—**BENIP; built environment; informaton platform**

I. Introduction

In the past half century there has been a great deal of discussion about the position of individual and teamwork and their role in science [1]; in relation to this it has been repeatedly argued that the era of lonely experts is over [2], [3], [4], [5], [6], [7], [8]. On the other hand, there is an increasing share of interdisciplinary topics spanning over several specialties accelerating the progress of research activities [9]. Furthermore, according to Barabási [10], based on the currently valid network models, our world is small enough for people to connect with each other employing a relatively limited number of steps. This concept was originally laid out by Karinthy saying that "any two people can be connected in a maximum of six steps" [11]. This was later scientifically phrased by Milgram [12] and proven by Guare [13] who also introduced the idea of six degrees of separation. Based on this thought, our world is indeed small and can be considered highly connected, not to mention how much data is gathered in the world every day [14].

Based on the above it seems logical that the information gathered in relation to the built environment should not be handled separately but could be shared for the benefit of all sectors. The built environment is a complex system surrounding us, human beings. There is always some sort of cooperation between its various fields and recently infocommunication has made these communication channels even more effective. A good example is Varga [26], who deals with traffic analysis using infocommunication techniques, or Nagy et.al. [27] who combine traffic-flow principles with a method from the field of infocommunication. These examples also made it clear, why it is important to handle problems in a holistic way.

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In this paper we introduce a new term called Built ENvironment Information Platform (BENIP). This concept aims to reveal the links in between the various domains of our built environment.

II. Definition of BENIP

Built Environment Information Platform (BENIP) is the concept of smart and system-oriented city planning and development spanning over the domains of architecture, civil, and transportation engineering integrated with the concept of Digital Realities such as virtual reality (including augmented reality, virtual and digital simulations and twins), artificial intelligence and 2D digital platforms thereby creating a highly contextual information platform.

BENIP shows the theoretical and practical aspects of the connected and chained world of engineering in the field of the built environment from the smaller entities of architecture (buildings) through the civil engineering domain (complex structures) to the expansive systems of transportation.

In the long term, BENIP would strive to be the main hub for scientists in fields of the built environment who interact with the interdisciplinary connections between architecture, civil engineering, and transportation. Specifically, as they relate to the generation, exchange and exploitation of data. Therefore, BENIP becomes an interdisciplinary meeting point for scientists and engineers of the built environment. Their general objective would be to foster the cooperation and information flow between the many engineering fields of the built environment.

III. Research fields of BENIP

The research fields of BENIP can be divided into two parts, the standard areas of built environment, and the Internet of Digital Reality (IoD). The concept of Digital Reality as a trademarked term refers to "technologies and capabilities that inhere in AR, VR, MR, 360° video, and the immersive experience, enabling simulation of reality in various ways" [20].

"Internet of Digital Reality (IoD) is a set of technologies that enables digital realities to be managed, transmitted and harmonized in networked environments (both public and private), focusing on a higher level of user accessibility, immersiveness and experience with the help of virtual reality and artificial intelligence. Connections among various cognitive entities also have to be handled not only at the end user level of virtual reality displays and software, but also at the levels of network protocols and network management, physical media (wired or wireless), hardware interfaces, and other equipment. AI is a key component of both digital reality and IoD, that enables a cohesion of context-driven content and intelligent network routing to emerge." [20]

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A simplistic definition by [15] says that the built environment is covered by the domains of outdoor spaces and buildings; transportation; and housing. According to [16] the built environment is more like a scale nature topic introduced at meso, micro, and macro scales. The built environment starts as a material or component form and grows into buildings, areas, cities, and finally a man-made environment of earth. [17] offers a broader view according to which the built environment 1) is everything humanly made, arranged, or maintained; 2) fulfills human purposes (needs, wants, and values); 3) mediates the overall environment; 4) produces results that affect the environmental context. [17] categorizes it into seven scales: products, interiors, structures, landscapes, cities, regions, and earth. In their study [18] the built environment scales are grouped into "Material", "Building", "Area", and "City". "Material" comprises all types of material and components while "Building" includes all types of structures, residential, non-residential, and infrastructure. "Area" represents the industrial parks and non-industrial areas that are smaller than cities but larger than facilities, and finally "City" includes both cities and large regions (see Fig. 1).

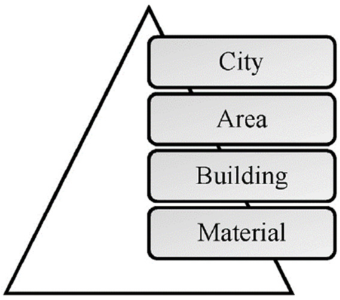

Fig. 1. Built environment scales [18]

[19] conceptualizes the built environment as a social-ecological system paying attention to two issues, the impact of spatial relationships and concepts of time. In their framework (see Fig. 2) where the natural and social overlap is in the built environment, which encompasses the fast changing, short-term processes – like design and management systems – within the constraints imposed by the features of long-lived buildings and infrastructure systems and the underlying land use patterns. Essentially the time rings for built environments provide a more systemic and graduated perspective on how time is valued (norms) and how elements of the built environment and ecosphere interact and influence each other. In Fig. 2. for built environments, the material and cultural realms are combined, with the fast pace of the social processes (design, assessment, contracting, management) balanced by the longer-term influences of buildings and landscapes.

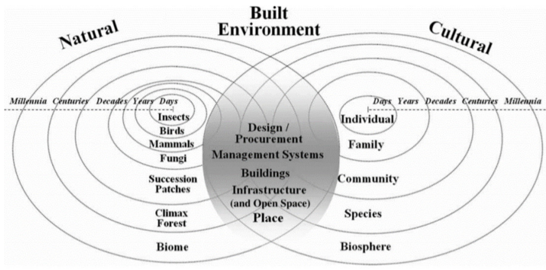

Fig. 2. Built environment as a social-ecological system [19]

Research fields of BENIP are also related to the Internet of digital reality (IoD) [20, 21]. Based on the definition of Baranyi et al. [20] IoD is a set of technologies allowing Digital Realities (DR) to be connected in networked environments, allowing a higher degree of user accessibility and experience. Here, the Digital Reality is an integration of virtual reality (including augmented reality, virtual and digital simulations, and twins), 2D digital environment (including all software and web applications, collaborative and cloud-based solutions) and artificial intelligence. This means, that a DR can combine physical, virtual and digital entities into a highly contextual reality. We can transform this idea into the world of BENIP as follows.

The different disciplines can be treated as separate Digital Realities, where each party is working on their own Virtual Twin (VT). This means a planned object has a 3D visualization in a different, usually computer-generated reality. This representation has different characteristics according to the disciplines: the focus, the scale and the level of detail vary along the architecture, civil engineering, and transport sciences. This Virtual Twin can be used for simulations to analyze various effects and compare alternative solutions. Here, the Virtual Simulation (VS) presents the 3D motion and changes in the geometrical 3D representation of the object, while the Digital Simulation (DS) demonstrates a temporal process, where the 3D representation is not in primary focus, according to [20]. For instance, in architecture and civil engineering the BIM method allows examining the deformations of the structure (VS), while also a life-cycle analysis can be made using the information content of the model (DS). The introduction of Digital Simulation into Virtual Twins means an extension of the existing model with the user interaction, which turns it into a Digital Twin (DT). This was a logical outgrowth of complex, but static simulations performing interference checks in industrial environments. These virtual and digital simulations and twins are components that can be integrated into a virtual or augmented reality. In architecture, the planned building (Virtual Twin) can be visualized in its real environment using augmented reality, just as the planned infrastructural object in transport sciences. With the help of different simulations, the interaction between the planned object and its environment may also be examined.

The Digital Reality of the disciplines serves as a medium (environment) of communication between the involved parties and uses various digital tools in an organized and specific, topic-oriented way. In relation to the BIM method, the concept of

Common Data Environment and its digital, internet-based solutions serve as the key element of the communication and collaboration along numerous participants.

It becomes Internet of Digital Reality, when these Digital Realities are connected via public or private networks in order to create a higher-level functional integration [20]. IoD bridges the gap between the disciplines and allows interoperability in a broader range. Here, the planned objects can be inserted into other Digital Realities, which enables more complex understanding of the interaction between the different disciplines. The combination of the architectural, civil and transport engineering realities connects the different scales: products, interiors, structures, landscapes, cities, regions, and earth. With the help of digital solutions (virtual and augmented reality), the smaller elements (products, buildings) can be visualized in a larger scale (city, region), as in the case of integrating BIM and GIS models and data. Furthermore, the virtual and digital simulations enable various analysis between these elements resulting in a dynamic relationship. At a city scale, the effect of a newly designed infrastructural or architectural element can be examined on the transport network and vice versa. When collaboration on 3D objects between several realities will become common in VR environments, it will also require the integration of big data and artificial intelligence [20]. As a result, it will be possible to filter and organize the entire information content to increase the efficiency of processes.

IV. Flow Of Information Between Research Areas

Based on what is drafted in the introduction, the continuously increasing amount of information as well as the connection between the specific disciplines it can be stated that Every coordinated and sustainable design for the built environment requires a timely and comprehensive transfer of data between multiple sources. This is nicely illustrated by Wanga et.al [22] in Fig. 3, where the flow of information links between various domains and strengths of connections are visible, where by the flow of information we mean knowledge transfer.

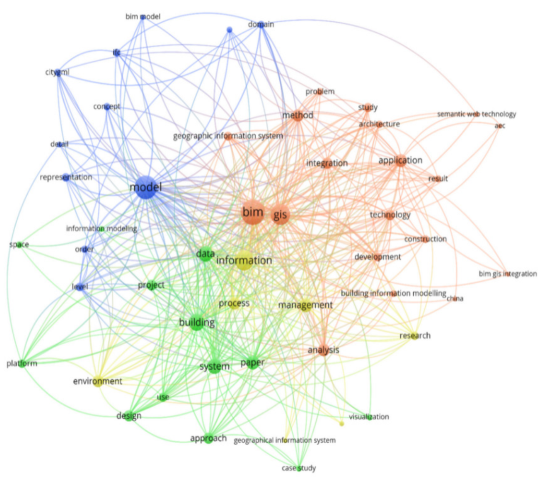

Fig. 3. Word co-occurrence network [22]

This figure clearly summarizes what we experience every day in our connected world. However, it masks the reasons and benefits hiding behind these numerous links. BENIP gives a meaning to these links.

If we focus closely on the built environment and its three associated disciplines, we can conclude that it describes the cooperation between architecture, civil engineering, and transport sciences. These three disciplines can be figured out as three set of knowledges, where all three are having specialized but also joint parts, like shown in Figure 4.

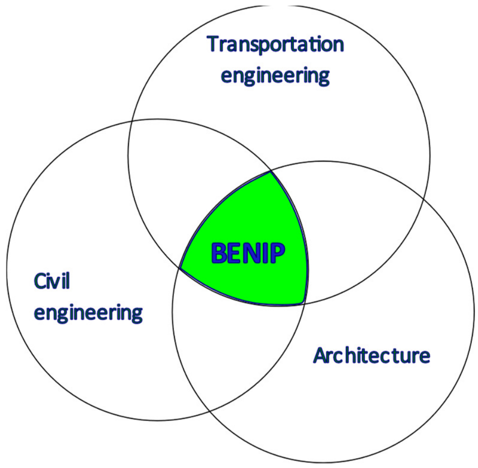

Fig. 4. Three major disciplines of the built environment

Based on our experiences this draft approach could be detailed with players and connections (relationships) as it is illustrated by Figure 5.

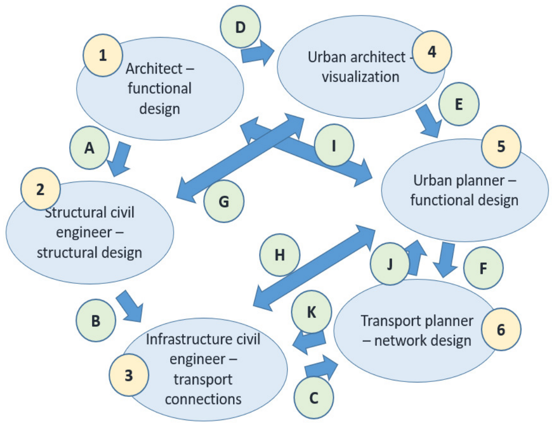

Fig. 5. Core of the BENIP logic

The various players and their relationship are described in detail in the following two sections.

V. BENIP Players

As figure 5 shows in the BENIP circle there are at least six groups of players. While the players may be ordered differently in different applications, all players are equally important. There is order from the viewpoint of the explanation, e.g. do we understand the story bottom up or top down? This discussion will show it bottom up, so we start from the small details and finish with the full picture, therefore the architect is the first player to be described.

1) Architect

The architect is the master in the creation of the building; the designer who provides building spaces with function. As a result of their work the function and the form of the building are created. Furthermore, he defines the position and orientation of the building according to the natural and built environmental factors as well as the aspects of the sustainable operation

2) Structural Civil Engineer

The structural civil engineer provides the building envisioned by the architect with a frame. As a result the structure of the building is created, which eventually influences its look and its general impression.

3) Infrastructure Civil Engineer

The infrastructure civil engineer provides the individual buildings with transport connections, they are responsible for designing the network around the buildings, thus extending individual buildings into the general built environment.

4) Urban Architect

This player formulates the atmosphere and the harmony of buildings, or as we might also call it, the city visualization. Furthermore, he does not only create a visualization but a living space as well.

5) Urban Planner

This player launches the functional relations in the city, defines the location and importance of individual social, economic, and practical functions. This is the player who induces life in between spots in the urban fabric. As a result, the functional areal units of cities are born.

6) Transport Planner

They are responsible for planning, regulation and operation of movement in the urban network by envisage of the provision for more or less space for transport. As a result of their work the network connecting the functions of individual buildings can become sustainable and environmentally friendly, if the regulatory frames enables sustainable transport solutions like walking, biking or using public transport as real competitors of private car usage.

VI. BENIP Relationships

Under this section the relationship between the above players is explained. These links can be either one- or two-directional, however, even opposing-competing links can exist.

A. The architect delivers the building features based on a **functional design** to the structural civil engineer. The form and function created by the architect has a great effect on the applicable structural types and materials.
B. The **physical location** of the buildings envisioned by the structural engineer will be the information based on which the infrastructure civil engineers work.
C. **Characteristics of the infrastructure** will provide the framework for the infrastructure civil engineer.
D. The **building design plan** based on the functional design provides a basis for the urban architect and vice versa. Since the building should be adapted into its surroundings, the city architecture may cause limitations or requirements to the architect in designing the form and façades, especially in case when cultural heritage has a presence in the area.
E. The **city visualization and atmosphere** made by the urban architect influences the urban planner’s functional design to a great extent. The natural and built environment, and the entire landscape has a significant impact on the usage of urban spaces, which should be considered in the functional design process as well.
F. The **functional layout** created by the urban planner serves as a basis for the transport planner’s work. It defines several requirements for the type of the applicable transportation systems and for their capacity.
G. The **city visualization and atmosphere** made by the urban architect will react to the structural design of buildings and vice versa: the applied structural type and material has a great effect on the visualization of the building, and therefore it influences the atmosphere of the entire landscape,, thus a mutual understanding is needed here.
H. The **functional layout** created by the urban planner as well as the **characteristics of infrastructure** mutually influence each other requiring a close cooperation. The urban planner defines the demands and needs of the infrastructure civil engineer, while the existing systems and environmental conditions have a significant effect on the range of applicable technical solutions.
I. **Characteristics and location of the functional areal units** stem from the **individual functions** created by the architect. The starting point for the architect is the functional areal unit. It affects the use of the urban spaces, therefore it influences the building orientation,

the position of the entrances and the connections between the different functions.

J. The transport planner connects the functional areal units by their use, thus **transport connections** react on the operation of functional clusters.

K. The transport planner is responsible for flow regulation and decide if the **requirements against transport connections** exceed their capabilities making them unable to ensure an appropriate connection, therefore the existing network system determines the possible solutions for the newly designed transport connections. If the existing capacities are not sufficient, the BENIP logic allows to go back to connection E or F to redesign the structure which will generate the transport demand.

Overall, the six players and the eleven links between them provide the basis for the appropriate flow of information in relation to the built environment. This, however, demands a common language that requires a uniform and standard description of information. This is not always self-evident or simple as described by Horváth et al. through a transport related example. This case revealed how complex and difficult it is to harmonize the methods of various disciplines. A well-known example is also BIM (Building Information Model), which is nowadays an accepted communication platform in the fields of architecture and structural design.

What the authors propose with BENIP is not a further expansion of BIM with the description of settlements and transport systems, but a new and complex language which can include the content of BIM, GIS as well as other data.

VII. Conclusions

In our connected world the cooperation of different disciplines and specialties is essential. The data driven society needs more and more information. These phenomena lead to the situation that even specialists need a more and better-connected environment. The answer for this challenge is the newly formed term: BENIP - Built ENvironment Information Platform. It provides a conceptual framework that handles all the relevant information of the built environment from BIM to GIS in one single system. CogInfoCom unifying both engineering and human-oriented perspectives can give more room to reach progress in developing this platform further. [23, 24]

On the other hand, we have to remark, that this conceptual framework is viable and sustainable if 1. the regulatory framework editors and decisionmakers are feeling the responsibility and necessity of conceptual and system-based approaches like BENIP and 2. the specialist using the benefits of system-based and data-driven planning and operation of built environmental systems, especially in urban environment.

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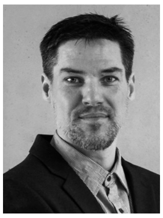

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The Cognitive Mobility Concept

Máté Zöldy and Péter Baranyi

Abstract—**Mobility is the engine of our society in the third millennium. Rapid technical development makes it possible to increase cognitive ability in various fields; mobility is one of the most affected. Mobility has become a multidimensional concept in our interpretation; in addition to transportation, it also appears in the digital space, among other dimensions. The 21st century has brought unprecedented challenges, such as the covid-19 virus and the Russian war in Ukraine. These highlight bottlenecks in mobility systems and prompted us to explore the concept of cognitive mobility. This paper intends to refine the CogMob approach, which co-manages human and machine capabilities in mobility. New achievements within CogMob's domain match the new challenges of war and viruses. This article aims to outline the field of cognitive mobility. It presents CogMob's definition and examples that clarify the combinations of cognitive levels of different mobilities.**

Index Terms—**Cognitive Mobility, Vehicles, Infrastructure, Digital mobility**

I. Introduction

Mobility is essential to our lives because we are constantly changing and moving. For many, the word mobility is primarily associated with transport, i.e., a change of location visible to the naked eye, often with the help of some means of transport. However, mobility can be much more diverse: for example, social mobility, which describes a change in the social situation of an individual or family, or labor mobility, which creates a link between a job and a choice of residence.

During the research and conceptualization of cognitive mobility, the focus of our attention is the deeper understanding of mobility with the help of cognitive tools. Transport mobility is a complex process that is preceded by the emergence of a need, the decisions to meet it, and its fulfillment. Essential elements of the used vehicle, the infrastructure, the environmental effects caused; time and energy; and resource demand in both the short term and historical time horizon. The result of mobility is the satisfaction of a trigger need or need and thus the creation of individual and social added value. Analysis of historical mobilities is a tool for a better understanding the present and the future.

Cognition and its mapping have long been a part and foundation of our lives. The rapid digital development of the 21st century allows us to expand our experiential learning with smaller, cheaper, and more sensitive sensors, data fusion, and artificial intelligence, with more and more data available [1]. Among other things, they help to get to know and map the world better and thus mobility. It also opens up new dimensions of understanding and development. Many focus on existing system components, but detailed empirical knowledge of the initial needs or the resulting value is becoming more common. This can lead to new solutions.

Getting better to know our world, our decisions, and our opportunities can, in extreme cases, mean minimizing or even giving up mobility, as we have seen with the Covid waves of the past year and a half or with new compact urban planning goals.

Previous use of cognitive mobility in the thought space has been limited to measuring the transition from one place to another [2, 3]. In our approach, this unique example of mobility is part of cognitive mobility and can be better analyzed and understood with this approach, but it is only a sub-segment.

The challenges of the second decade of the 21st century, which are very different from the trend of the last seventy years, such as the Covid virus and the Russo-Ukrainian war in the EU, also pose a mobility challenge. Not only energy problems, from natural gas to oil to nuclear energy, the collapse of logistics chains, the slowdown in vehicle production, and the production of sensor systems affect new and existing systems.

The evolving artificial knowledge of human cognitive abilities and machines is becoming increasingly fused in mobility. This article seeks to refine further [4] the perspective of a framework in which human and machine capabilities are part of a mobility system.

II. Definition

Cognitive mobility (CogMob) examines the intertwined combination of research areas such as mobility, transport, and its management, vehicle manufacturing, related social sciences, artificial intelligence and its applications, and cognitive info-communications. The main goal of CogMob is to give a holistic picture of mobility and its broad understanding. It thus describes, models, and optimizes as a mixed combination of artificial and natural/human cognitive systems. It sees the whole combination as an inseparable CogMob system and explores what new cognitive abilities come from this CogMob system. One of CogMob's focus areas is, of course, engineering applications in the mobility sector.

Two critical dimensions of cognitive mobility need to be identified: the ranking of mobility and the elements of mobility.

The ranking of mobility is a hierarchy with two purely theoretical endpoints. These refer to the cognitive level of those involved in mobility.

• Intracognitive mobility - participants in mobility have almost similar cognitive abilities (e.g. pedestrians on a pedestrian street or otherwise moving goods in a warehouse)

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• Intercognitive mobility - mobility participants have different cognitive abilities (highly automated vehicles and bicycles travel in urban environments).

The elements of mobility are related to the essence of mobility:

• Necessity of initiative: this is the reason behind mobility

• Decision: Influences how mobility occurs, whether it happens at all or not. It can occur more than once during an activity.

• Device / vehicle / quality: different quality parameters that influence the decision, the resource requirement, and the result of the mobility.

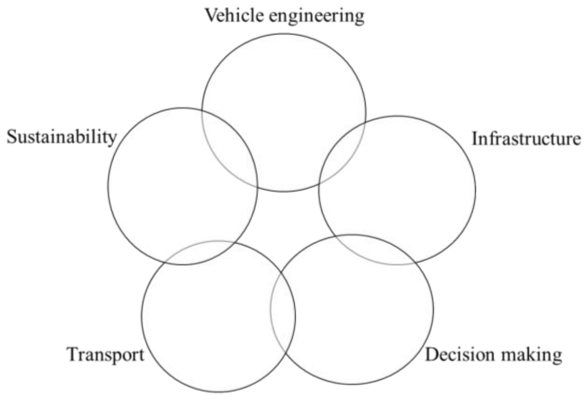
• Infrastructure / Resources: In addition to infrastructure, mobility consumes many resources, such as money, time, energy, etc.

• Human-machine interface: includes a wide range of options, from smartphones, smart maps, web tracking interfaces, simulation software, and more.

III. Key areas of mobility

In the discussion section, we examine the research areas related to CogMob from a historical perspective. This chapter highlights the growing role and influence of natural and artificial cognitive processes in mobility science. It shows that people and the environment are increasingly merging in mobility and offers us a "one-size-fits-all" modeling space that makes it easier to understand mobility.

Historically, research areas related to mobility have been fragmented into silos and run in parallel with a small number of interdependencies. Most of the research focused on their own area of focus and treated the rest as peripherals and endowments. The rate of mobility development has increased in the 20th century, similar to the acceleration of many areas of life. The main areas were automotive, infrastructure, road planning and decision making, transportation science, human-machine communication, and social sciences. This has been complemented by the theme of sustainability in recent decades. The parallel technological development of these sciences has reached the point where more and more synergies have been achieved through in-depth collaboration (Figure 1).



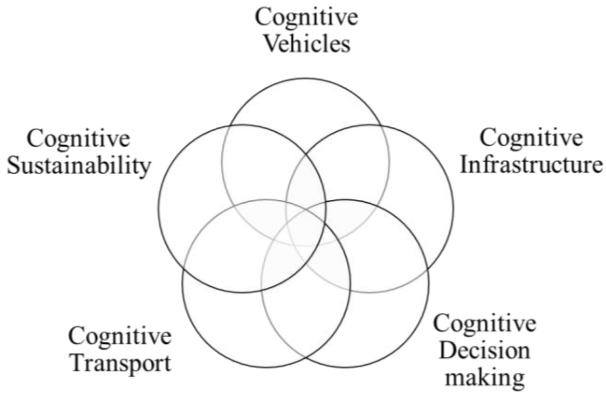


Fig. 1. The key areas of mobility have a higher level of synergy, and the areas come together to develop more effective cooperation.

Interdisciplinary collaboration is growing, as vehicles, for example, used to be mere infrastructure users, but today infrastructure and vehicles work together to provide input for decision-making and route planning.

A. *Cognitive Vehicles*

The growing importance of safety aspects was the first driving force that positively affected the cognitive level of vehicles. Safety devices were mainly mechanical aids for the driver in the beginning. In the last decades, driver assistance devices' role in vehicles has increased [5]. In 2019, a cognitive vehicle engineering workshop was held. The focus was on the human inspiration for perception, learning, and decision-making that could be transferred to increase the intelligence of vehicles and other autonomous systems in the future [6]. They focused on the potential benefits and pitfalls of using artificial and natural approaches in the design of intelligent systems that perceive, interact, learn, and make decisions.

B. *Cognitive Infrastructure*

Historically, the reason for building new transport infrastructure was commercial intent. The ancient Silk Road or the Roman military roads are examples of this, but the Panama Canal or the first railroads were built for a similar purpose. At the beginning of the 20th century, there was a similar motivation behind constructing the electricity network. Although these included complex systems, they are independent tools that facilitate the movement of goods. On the other hand, cognitive transport infrastructure is a meta-infrastructure; it contains many interconnected, and thus continuously interacting, factors. The interconnection aims to increase capacity utilization through several previously unavailable technologies such as 5G or even 6G communications networks, artificial intelligence and big data analytics, social media, Internet-connected devices, or cloud-based storage. The spectrum of users and developers is also complex, as elements of the cognitive infrastructure are developed and used by individuals, companies, and public institutions [7]. The complexity of communication between infrastructure and users is increasingly similar to communication between people. The knowledge accumulated in one area can be transferred to another [8].

C. Cognitive decision making

Decision-making is essential not only for increasingly automated vehicles but also for driver support. Intensive research is also underway in this area. In the field of transport decisions, cognitive memory is of paramount importance. Continuous, dynamic redesign of the route by adding cognitive factors is an excellent example. The goodness of the decision results was greatly improved by reducing the error, indicating that the vehicle was able to learn cognitive variables. It opens up the possibility of unsupervised learning in making sensible transport decisions. Decision-making about vehicles is cognitively similar to the human mind, which also maps the classification of events to processed patterns.

Exploring other features of human cognition, such as emotions and memory structure, offers another exciting way into the future. Unsupervised learning is an essential cornerstone in the development of self-driving vehicles. Data mining can also facilitate routing; however, an optimized mining strategy is required to select selective data [9].

D. Cognitive Transport

Deploying intelligent transport systems is one of the biggest challenges of traffic planning in the 21st century. Developing cooperation between conventional and autonomous vehicles at different levels of the global transport system is a task now and soon. Already in this decade, the proportion of self-driving vehicles, the heterogeneity of traffic, and the distribution of vehicles and transport infrastructure are increasing to ensure their effective control and to improve the quality of the transport services provided. Creating a cognitive multimodal transport system is a complex example of the intellectualization of vehicles, transport infrastructure, and the systems and networks that connect them. The main driver of this process is the artificial intelligence factor in transport systems. A successful system dramatically improves the safety of people and cargo, reduces the average time of passenger and freight transport, improves the efficiency of the use of the capacity resources of the national transport system for a higher level of environmental safety, and has a significant impact on the national economy. Together with the latter result, it can be stated that the development of a cognitive multimodal transport system gives a strong impetus to the general development of the national economy [10].

E. Human-machine communication

The history of the human-machine interface (HMI) is closely linked to the history of driving. The first international conventions on the HMI of vehicles were concluded in the 1949 Geneva Convention on Road Traffic [11]. The Gefi agreement contains, among other things, rules and recommendations for the vehicle's internal HMI. For example, a speedometer and steering wheel must be installed in the vehicle.

A significant step was the emergence of routing assistance systems in the 1970s. Subsequently, the first generation of driver assistance systems and the increasingly complex systems that followed increased communication between the driver and the vehicle. Early driving support systems, such as ABS, ASR, ESP, were already in use at the end of the 20th century, but by the turn of the millennium, a 'cruise control' was introduced to handle tracking distance. There was a significant breakthrough in management support systems in the early 2010s with the advent of complex systems [12]. One sign of this was the growing screens and onboard displays. Communication between the infrastructure elements and the drivers has intensified. In most sub-sectors of traffic, the driver cannot be excluded from mobility, but the functions that partially enable autonomous driving require increasingly complex communication, which encourages the development of communication interfaces.

F. Cognitive Sustainability

Sustainability is a crucial dimension of life at the beginning of the third millennium. Our society transforms and changes even faster and more continuously than any earlier. Mobility is part of the rapid change; sometimes, it is the accelerator. Sustainability aspects are crucial for mobility as society is highly dependent on mobility [13].

Above all, CogMob is a holistic approach that, in addition to examining mobility in the context of artificial and natural cognitive skills, also supports its view of the social sciences, thereby facilitating a deeper, more comprehensive understanding and understanding of mobility. The interaction between mobility and economic processes is a clear link for everyone. Understanding mobility, using the tools of the social sciences, provides an opportunity to learn about and understand the processes behind mobility. A deeper knowledge of the social processes that emerge through mobility can provide an input variable for further mobility development.

The goal and mission of CogMob is a holistic mobility approach that is greatly facilitated by information communication tools. It connects certain aspects of the system, such as decisions, infrastructure, and tools. CogMob provides a shared space for optimization through the conscious and well-chosen use of IT tools, considering system components as part of a cognitive system [4].

IV. Cognitive mobility in practice

In this chapter, some examples are provided that clearly show the combination of cognitive levels, mobility modes, and mobility elements.

A. Augmented security of connected vehicles

In the automotive industry, cybersecurity is an emerging area of research in these years that many are approaching from various perspectives [14]. Existing vehicle safety solutions cover a wide area, often with competitors doing the same thing differently. State-of-the-art and future research directions. Based on the results of a wide-ranging analysis covering the topic, the field of artificial intelligence and defense mechanisms was previously underrepresented in research. Therefore, we can expect a wide range of interest in these areas. Another current area is vehicle communication, which dominates most of the developments.

B. Merging of info-communications and mobility

Digitization affects vehicles, drivers and infrastructure, and vehicle occupants. A study has revealed [15] what activities are carried out during non-local journeys, mainly on various means of public transport such as train or city and suburban buses. In summary, it can be emphasized that - based on one of the first travel-based multitasking studies in Hungary - the proportion of activities performed on non-local trips on a smartphone or tablet starts from a low level but is constantly increasing. This process correlates with smartphone ownership and mobile internet access. On the one hand, the main finding is that the use of electronic devices decreases with age [15].

C. *Hybrid and electric propulsion systems*

In addition to vehicle control, the use of artificial intelligence has also advanced in the driveline. Internal combustion engines are increasingly challenged by more stringent standards [16]. With the development of in-vehicle electronics, components such as brake assist, exhaust gas recirculation, and steering can be controlled so that previously unavailable operating conditions are available. An example of this is the intelligent engine control system [17], which can achieve optimal performance even in extreme conditions. In addition, a supporting vector-machine-based forecasting model has been developed to predict engine performance under varying operating conditions. The developed, supported vector machine model predicted the engine's performance with high accuracy.

The application of statistical regression models has also appeared in vehicle development. A three-step statistical analysis algorithm using vibration and sound pressure data as covariates to predict exhaust gas composition has become demonstrable [18].

Machine learning results can also be applied in vehicle control, especially in the control of self-driving vehicles. The road tracking function is required to guarantee vehicles' safe speed and movement profile with variable tire-road contact. The solution for this case combines Linear Parameter-Varying (LPV) control integration and machine learning-based analysis. The integration takes place in two steps. The result of the estimation method is generated using the coefficient of adhesion decision trees. The estimation result is integrated into the robust LPV controller via a scheduling variable. An error in the machine learning algorithm is built into the design of the control. In a second step, the optimization of longitudinal velocity is proposed over a predicted horizon, with a defined approximation of the accessibility of steering intervention based on machine learning [19].

D. *The digitalization of the infrastructure*

The cognitive approach is also playing an increasingly important role in water transport. In addition to navigation infrastructure, ports are the ones whose development is tangible. Improving digitization means increasing efficiency, so this can be seen as the main direction of development. Ports have different levels of digitization. Many reasons for this can be, for example, the size of the port, its history and traditions, and the size and type of traffic. A different methodology seeks to bring together the different levels and related developments [20]. Ports were compared within groups of small, medium, and large ports. It is estimated that the level of digitization in small and medium-sized ports is around 30% lower than the level of large seaports. The research results may be of interest to ports seeking to assess the level of their digitization and select the best digital development solutions.

E. *Onboard energy management*

A complex example of cognitive vehicle technology is vehicle recharge management. The importance of this topic area is growing with the development of self-driving skills of vehicles. It is currently unknown what will be the primary vehicle propulsion in the coming decades. The most complex of the available technologies is plug-in hybrid technology: it combines an electric powertrain and a conventional internal combustion engine, in the latter case with renewable [21-24] or even synthetic [25] propellants. In the case of fossil fuels, communication between filling stations and vehicles is a one-way, narrow channel, providing information on fuel prices only.

In contrast, mutual communication allows joint optimization in terms of route, fuel, charging time, and even price [26, 27]. For example, the longer charging time of electric vehicles, and therefore the waiting time due to the charging needs of others, as a decision criterion, will only be possible with better quality and quantity of communication between systems. Waterborne transport and the use of agrofuels open up further areas for improving the optimal energy management of vehicles with cognitive tools [28].

F. *Environment perception*

Perceiving and understanding the environment is a central area of automotive development in the 21st century. This solution is of paramount importance not only in self-driving vehicles but also in the driver assistance devices of conventional vehicles. These systems are suitable for processing and managing dynamic relay systems such as controllable signals, adaptive traffic control with traffic lights or even traffic news information. Connecting in-vehicle systems with intelligent infrastructure increases the range of possible decision options. Because the critical input parameter of self-driving and driving support functions is perception, since driving is based on the results of different sensing algorithms, perception can be broken down into subproblems. The most common are lanes, traffic signals, objects, environment, etc. These solutions based on artificial intelligence, primarily neural networks, are already close to applicability today, and we will encounter them more often in the future [29, 30, 31].

G. *Digital twin-based research*

Intermodal transport infrastructure is a good example of cognitive elements' growing and increasingly important role. An increasingly important element of urban ecosystem models is the design, even optimization, and shaping of mobility. The relationship between urban structure, mobility, and urban development can be identified using cognitive tools. Cognition can be facilitated [32]. Simulation of mobility infrastructure also plays a key role in vehicle development.

This is necessary concerning the development of transport simulations and, on the other hand, for increasing mobility safety. Continuous updating traditional static maps is resource-intensive and opens the door to computer simulations [33]. Due to their technological solutions, self-driving vehicles are almost impossible to integrate into the cumbersome homologation procedures of conventional vehicles [34]. Their long development time can be radically reduced, for example, by using digital-twin solutions [35], in which validation can be performed at any time due to simulation and the parallel running of reality.

H. Intermodality decision making

In mobility, cognitive methods can help make instantaneous decisions. Roundabout has long been used as an intersection solution due to its easy adaptability and high level of safety. In the case of self-driving vehicles, in many cases, one of the main directions of development is the highway scenario; the work in the roundabout requires more time and effort. Research demonstrates the usability of various decision support applications, making it clear that cognitive techniques increase efficiency [36]. Driving wants to avoid collisions and minimize energy consumption. The optimization tasks are interrelated, i.e., quadratic optimization with the vehicle model is used as the environment during training [37]. The application of new cognitive approaches is necessary not only in the ground but also in air mobility. In unmanned aerial vehicles, new applications are very similar to self-driving cars [38].

In intermodal transport, harmonizing sub-sectors can also be interpreted as a complex treatment of the above. These improvements will also increase the level of transport efficiency and sustainability. Research [36] collects and analyzes the factors that have identified ten factors influencing the efficiency and sustainability of intermodal transport.

Conclusions

At the dawn of the 3rd millennium, mobility is one of the foundations of the way of life. The CogMob concept presented in our article consciously focuses on deepening and extending this. The mobility dimensions presented in the article (ranking of mobility and elements of mobility) help to interpret the broad topic of mobility from a cognitive perspective. The examples illustrate the importance of the cognitive approach in many areas and parts of mobility. CogMob explores the similarities between work in each subject area, looking for a holistic framework for managing natural and artificial cognition in one system.

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His main research interests include cognitive sustainability and cognitive mobility with special focus on vehicle and fuel technologies. He plays a leading role in the development of these disciplines.
He is the chair of the IEEE Cognitive Mobility Conference.

Péter Baranyi established the Cognitive Infocommunications concept around 2010. It is a scientific discipline today focusing on the new cognitive capabilities of the blended combination of human and informatics. It has an annual IEEE International Conference and a number of scientific journal special issues. He invented the TP model transformation which is a higher-order singular value decomposition of continuous functions. It has a crucial role in nonlinear control design theories and opens new ways for optimization. He is the inventor of MaxWhere which is the first 3D platform including 3D web, 3D browser, 3D store, and 3D Cloud. His research group published a number of journal papers firstly reporting that users get 40-50% better effectiveness in 3D digital environments. These results got a very high international impact within a few years.

Design and Development of a User-Centered Mobile Application for Intermodal Public Transit in Bangkok: A Design Thinking Approach

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***Abstract*—With the constant increase in public transit coverage in Bangkok Metropolitan Area in Thailand, many people are still hesitant to switch from using private to public transit, with one potential cause being the unavailability and difficulty in accessing accurate and timely information about their itineraries, while they are commuting. To assess and tackle such issues, the researchers adopted the user-centric Design Thinking methodology to empathize with target users' pain points in this study. They proposed a solution in a user-centric manner by assessing the usability flaws of existing mobile navigation applications, such as Google Maps and ViaBus. By developing a holistic mobile application called '*Disgovery*' that covers all modes of public transit in the Bangkok Metropolitan Area and provides relevant information about their trips, the researchers aim to help commuters in Bangkok easily access it in a timely fashion. Through the user-friendly interface, commuters can eliminate the difficulty of finding routes and prices suitable to their needs. By making public transit more accessible with the help of ubiquitous mobile computing, commuters are also encouraged to switch from using private vehicles to public transit, which also can reduce accidents and carbon emissions. The findings from the usability testing in this study suggest that '*Disgovery*' is an effective and user-friendly application for daily commuters in Bangkok that can help them achieve their goals without difficulties. The findings also indicate the importance of user interface and user experience guidelines in designing such applications.**

***Index Terms*—Mobile Application for Public Transit, Bangkok Public Transit, Public Transit, Route Description, Route Instruction, Intermodal Public Transit Navigation, Navigation Application, Routing Algorithm for Public Transit, Design Thinking**

I. Introduction

Bangkok is known to have one of the worst traffic in the region. In modern-day Bangkok, as road traffic condition has been so deteriorating, the wide coverage and development of public transit in this metropolitan city should be prioritized [1]. To tackle this issue, there have been several public transit construction projects planned to be completed and spanning over 30 years [2]. The current public transit in Bangkok includes buses, MRT (Bangkok Metro), BTS Skytrains, and water taxi or boats. Over the past decades, the existing modes of public transport have been upgraded to be modern and convenient; however, many people in Bangkok are still driving their private cars instead of using public transit, leading to an ever-increasing number of car ownership and road accidents, which have become a significant concern for the authorities. One possibility is that there is a lack of reliable, accurate, and accessible sources of timely information for daily commuters to plan itineraries via public transit. Most of the existing tools people use are mobile applications, including Google Maps and ViaBus. Despite being widely used, these current mobile applications do not provide a holistic solution—i.e., complete, accurate, and timely relevant information—to the users, with some lacking pricing information and most being inaccurate (e.g., time) and insufficient (e.g., cost).

With the increased availability of mobile devices and countrywide access to high-speed Internet in Thailand, many people have become reliant on mobile-based applications to perform their daily tasks, including banking, education, and communication. Hence, a mobile-based solution has shown promise to address the needs of public commuters in Bangkok to access more reliable, accurate, and timely public transit information. Furthermore, although ubiquitous mobile computing for public transit has been in research for a few decades, the study is limited in user experience and usability of such applications. It can be noteworthy to research if a user-centric interface design and user-friendly experience would be a driving factor to an effective solution in user-centric system development. Hence, this study aimed to alleviate the difficulty in itinerary planning involving public transit in the Bangkok Metropolitan Area by providing personalized and accurate information on prices, timetables, transfers, and public transit modes in Bangkok Metropolitan Area as a mobile application. Furthermore, we are interested in understanding the role of usability and user experience in adopting such a mobile-based application.

In recent years, due to the advances in ubiquitous communication technologies, cognitive infocommunications (*CogInfoCom*) has become an important research area in which researchers have studies how users' cognitive processes can co-evolve with infocommunications devices such as mobile and tablets [22]. According to [23], *CogInfoCom*, which is a relatively young research area, has common interests with other disciplines including human-computer interaction, affective computing, ubiquitous computing, artificial intelligence, and so forth. Over the past decade, researchers have conducted studies related to this specific research area in *CogInfoCom*, for example, in [24], the researchers designed and developed a gamified system to

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improve the elderly people's mental wellness in terms of their cognitions (e.g., memories and learning). Also, in [25], the researchers studied how users engaged in immersive virtual reality spaces (VR), as well as their cognition in interacting with such VR systems. Similarly, in [26], the researchers reported the importance of user's cognition in using VR-based exercise systems for their physical health.

As the existing literature has clearly shown the importance of user's cognition in using communication systems, one of our study's objectives is to understand how the interface design of our system can affect users' cognition. Hence, to achieve our study objectives, the researchers in this study adopted the '*design thinking'* methodology to design and develop a user-centric mobile application that tackles the issues discussed earlier. During the process, the researchers would gain in-depth requirements and needs of the users through empathy-based user research, followed by designing and developing the application that conforms to the user experience and interfaces design principles. Eventually, the software would be tested and evaluated by conducting usability testing in a controlled setting. The findings from this study can be useful for designing and developing a mobile-based application for public transit in Bangkok and other cities worldwide. Being a design case-study using design thinking methodology, this study aims to contribute to the scientific community particularly in human-computer interaction and cognitive infocommunications research areas in terms design recommendations for future research.

II. Literature Review

According to the literature [3], the study estimated that the traffic demand from East Bangkok would far exceed the transportation supply. The researchers also indicated that extending the current public transit system could alleviate numerous issues caused by the excess demand in traffic in Bangkok. With the tendency of traffic demand in Bangkok to increase, there are also plans to accommodate the commuters. Namely, several mass transit systems on the rail will be under development and construction in 2022 [2]. The rapid expansion of mass transit systems means that commuters may have better and more convenient options for traveling; however, it is also a challenge for them to handle all the relevant information and familiarize themselves with the new transit lines and extensions that are opening more frequently than before [2]. The literature also highlights that when it comes to modern technologies for public transport systems, accessibility is one of the central clusters of issues persisting in all Bangkok public transit systems [4]. For simplicity, the problems can be subdivided into ones concerning intra-modal transit and others relating to inter-modal transit.

Regarding the intra-modal accessibility of Bangkok public transit, Noichan and Dewancker [4] 's analysis of BTS' Mo Chit Station, Victory Monument Station, and Saphan Taksin Station suggests that mass transit nodes in Bangkok still lack accessibility, especially on the inside of the station buildings. Accessibility gaps in wayfinding within a station building are one of the main issues for which this study aims to provide a solution. On the other hand, in terms of inter-modal accessibility, Amrapala and Choocharukul [5] mentioned the informal public transport service, "*Silor*" (literally "four-wheeler" in Thai), being the leading choice of mobility for connecting between larger public transit nodes. Apart from Silor, tuk-tuks and motorcycle taxis are popular for informal transit [6]. This suggests a higher flexibility and sophistication in intermodal transit in Bangkok since commuters may connect between transit modes by walking and informal public transport services.

Due to advances in ubiquitous computing, mobile devices have become integral to everyday life. Consequently, the mobile network plays a crucial role in connecting mobile devices to the internet, but limited literature exists exploring mobile network coverage in Bangkok. Regarding [7], although the network quality (measured in terms of download speed) is inferior compared to other countries (ranked as 77th out of 87 countries), Thailand has a mobile network signal that covers 95% of its area with acceptable speed (5.7 Mbps), which can provide access to virtual map at ease. Wi-Fi is an alternative way to access the internet used by 58.18% of Thai people, which is the majority compared to mobile, dial-up and hotspot [8]; thus, Wi-Fi availability in Bangkok has to be taken into consideration. As mentioned in [9], the Wi-Fi coverage area in Bangkok covers the entire city; however, the Wi-Fi used while transporting provides only a 55% successful transmission rate. Regarding mobile accessibility, 80% of people in Bangkok aged between 25 and 34 (the target group of this study) own at least one smartphone or mobile device [10]. All the repercussion above indicates that commuters in Bangkok have sufficient needs that support them to use virtual maps over paper maps.

The increased demand in traffic still cannot be fully resolved with the expansion of public transit lines since the experience of using public transit is limited to the poor design of the stations and the lack of data integration between operators. With the prominence in accessibility issues that seems to be expanding alongside the new transit line openings in Bangkok, there is still no research to integrate information accessibility among different public transit systems in Bangkok. Hence, in this study, we aimed to design and develop a user-centric system for intermodal public transit in Bangkok while considering the importance of usability and user experience in it.

III. Design Thinking

The Design Thinking approach is a user-centric way of designing and developing a solution, which consists of 5 main phases—empathize, define, ideate, prototype, and test [11]. Design thinking has been widely accepted by many designers and UX researchers worldwide, as it has been applied in many areas, including engineering, interaction design, business, and policy-making. To create an innovative solution for specific user groups with distinct needs, the Design Thinking approach allows us to genuinely empathize with the target users and develop a solution that effectively solves the users' problems and needs. Per this study, the researchers adopted the Design Thinking approach to gain insights into the problem space regarding public transit users in Bangkok to walk through the solution space appropriately.

A. Empathy (Understand and Observe)

In the *'Empathy'* phase, the problem statement was first formulated—commutes via public transit in Bangkok are inconvenient and burdensome—with target users of regular commuters whose commute regularly consisted of public transit. The researchers then gathered user requirements qualitatively by conducting interviews with a predefined set of questions and quantitatively using a questionnaire. The interview questions consisted of four parts: methods of transportation, itinerary planning processes, everyday issues of public transit, and applications and tools used to assist traveling via public transit. Each user interview session per participant took 40 minutes on average, and all participants were requested to confirm their consent to be recorded, strictly only for further usage in this project's scope.

As a result, the interview responses from 8 participants helped identify several issues with the public transit systems in Bangkok. The problems mainly included the frequent unpredictable delays on the transit systems, non-centralized information of routes, prices, and timetables, and poor user interface designs on existing public transit applications. In addition, the questionnaire results highlighted the issues concerning the public transit navigation systems, i.e., Google Maps, Apple Maps, ViaBus, and BKK Rail. The survey also let the participants pinpoint the severity of the problems in different aspects of each system using a 5-point Likert scale to score the techniques in each element, i.e., ease of use, time accuracy, route correctness, completeness of information, system performance, and bus location tracking accuracy (ViaBus only). From the questionnaire with a sample size of 47, it is found that most users are familiar with Google Maps (89.4%), followed by ViaBus (31.9%) and Apple Maps (29.8%), and lastly, BKK Rail (6.4%). Similarly, the average satisfaction score for Google Maps is highest at 3.91 out of 5 points, followed by ViaBus (3.60), Apple Maps (3.37), and BKK Rail (2.83). The user satisfaction scores of all existing systems were below 4 points, which is 80% of the total score. The findings from the initial user research confirmed that the current systems could not cater to the needs of public transport commuters in Bangkok in terms of adequacy, accessibility, and timeliness.

B. Define

After the user requirement gathering processes were completed, raw data from the user research was analyzed and transformed into graphical visualizations representing the satisfaction scores of each system. The interview results were convoluted into an empathy map, and a persona associated with the responses was created to represent the target users of the system. An empathy map is used in the '*Define*' phase to capture what users encounter daily, along with their pains and gains. Followed by the empathy map, a persona, a fictional character, was created to represent the target users of the system as a person with personal backgrounds, goals, needs, pain points, and personalities. For this study, a persona of an undergraduate student in an urban university who must regularly commute to the campus by public transit was created to represent the users who would benefit from this study. Following the persona, a user journey map—a tool that allows the authors to identify the user's thoughts, actions, and feelings across chronological phases while undergoing certain situations—was created to depict the as-is process of using public transit in Bangkok.

After the persona was created and the user journey map was illustrated, the researchers formulated the *How-Might-We (HMW)* questions in accordance with the persona's needs to narrow down the scope of the solution to be implemented in succeeding steps. The HMW question in this study was, '*How might we help daily commuters in Bangkok gain access to accurate, reliable, and timely information about their travel plans through a user-centric and user-friendly interface?*'. Furthermore, the specific user needs were brainstormed and generated from the empathy map, persona, and user journey map. The users' needs included accurate Time and price estimates, intuitive navigation, route comparison, and delay notification.

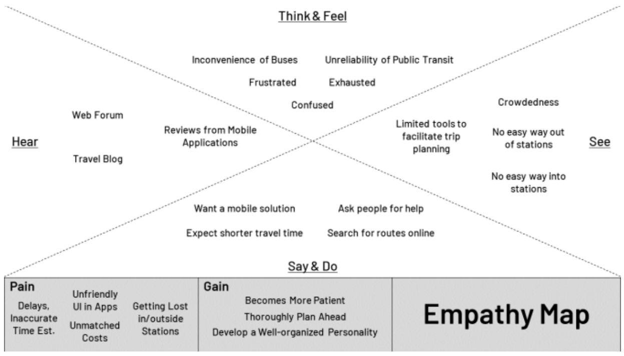


Fig. 1. Empathy Map

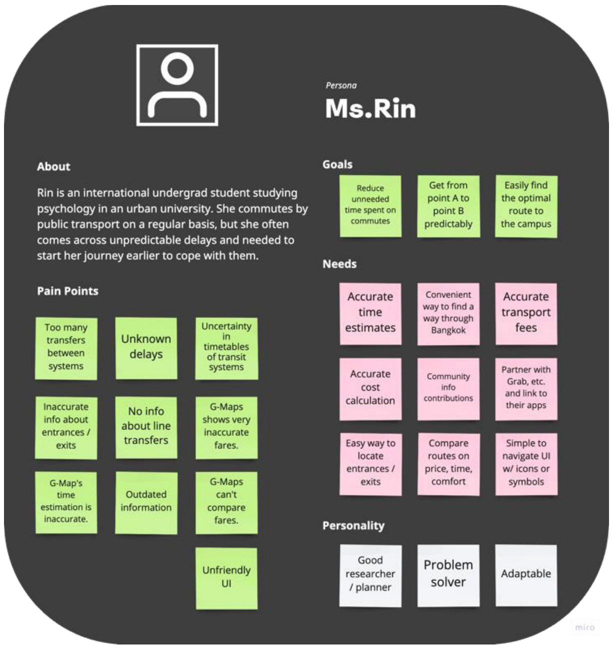
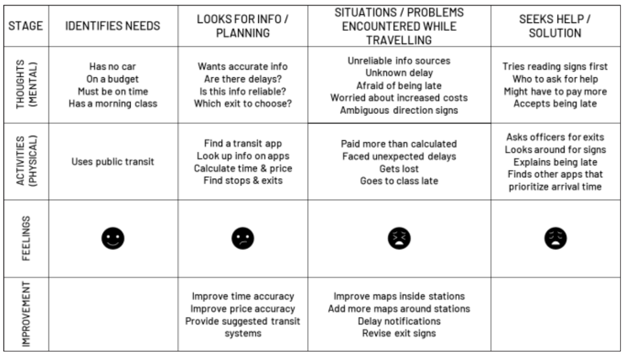


Fig. 2. Persona



STAGE	IDENTIFIES NEEDS	LOOKS FOR INFO / PLANNING	SITUATIONS / PROBLEMS ENCOUNTERED WHILE TRAVELLING	SEEKS HELP / SOLUTION
THOUGHTS (MENTAL)	Has no car On a budget Must be on time Has a morning class	Wants accurate info Are there delays? Is this info reliable? Which exit to choose?	Unreliable info sources Unknown delay Afraid of being late Worried about increased costs Ambiguous direction signs	Tries reading signs first Who to ask for help Might have to pay more Accepts being late
ACTIVITIES (PHYSICAL)	Uses public transit	Find a transit app Look up info on apps Calculate time & price Find stops & exits	Paid more than calculated Faced unexpected delays Gets lost Goes to class late	Asks officers for exits Looks around for signs Explains being late Finds other apps that prioritize arrival time
FEELINGS				
IMPROVEMENT		Improve time accuracy Improve price accuracy Provide suggested transit systems	Improve maps inside stations Add more maps around stations Delay notifications Revise exit signs	

Fig. 3. User Journey Map

Fig. 4. To-be system

C. Ideate

In the design thinking process, the *'Ideate'* phase is the process that consolidates ideas that contribute to the ultimate goal of creating a solution for each of the observed problems. Specifically, the method comprises the translation of solution ideas into functionalities or requirements of the system. This study discusses five user needs that take the form of solution ideas, which are translated into system requirements and functionalities. The most mentioned user's need was the accurate time information of the transits, and the solution idea for which is to frequently and regularly update timetables referring to the transit operators and research the "*Time*" required to transfer between each transit line. However, with the time and human resource limitations, the study only scopes the transfer research to transit stops with multiple transit lines, e.g., MRT *Tha Phra* and BTS *Siam*. The solution is translated into the system's functionality to display the expected time duration the user would spend on the trip shown.

The second proposed idea was regularly updating fare information for each transit line. Since public transit fares are occasionally discounted or waived with regard to national holidays [12], [13] and increased to match the rise in operational energy cost [14], a system requirement was formed such that the fare information should be regularly monitored and updated. The fare of each trip should also be accurately calculated and presented on the system accordingly. The third solution proposed was the turn-by-turn navigation system that would intuitively lead the users from their original locations to their destinations. Being prominent for almost 15 years, the turn-by-turn navigation system has proven itself through Time and has gone through much refinement until today [15]. A system requirement, design-wise that would accommodate such a solution idea would be to model from and improve upon an already existing turn-by-turn navigation system, e.g., Google Maps and Apple Maps, not only to provide familiarity in the user's journey but also customize the visual design to be more appropriate for usage in public transit. Due to their more straightforward nature and fewer details needing to be discussed, the other two solution ideas with their corresponding system functionalities and requirements are listed in Table I, alongside the solution mentioned above idea translations. With regards to the system functionalities and

TABLE I
FROM SOLUTION IDEAS TO SYSTEM'S FUNCTIONALITIES

Solution Idea	System Functionality / Requirement
Sufficient timetable updates	Display time obtained from transit operators; frequently and regularly check for timetable updates
Sufficient fare updates	Regularly monitor updates for fare rates, first entry costs and cross-operator integration adjustments, and promotional discounts of each transit operator; calculate fares by referring to existing rules and display on trips accordingly
Intuitive navigation system	Turn-by-turn navigation modeled after existing, widely used systems with minor adjustments and improvements to be more suitable for public-transit-based navigation
Trip personalization	Compute trips with priorities put on different preferable aspects of each user, e.g., Time, cost, fewer transfers, and allow users to choose from the list of offered trips to the same destination
Delay information updates	Provide real-time delay notification based on real delay data fetched from the transit operators—the information package includes the transit lines affected, transit stops or areas where the delay is caused, and expected delay time.

TABLE II
UX/UI PRINCIPLES APPLICATION

Principle	Application
Jakob's Law	According to the survey, design elements resemble those of Google Maps and Apple Maps, which is familiar to many people.
Fitt's Law	The most important actionable targets/buttons are prominent in size and placed vertically on the screen.
Hick's Law	Each page only contains a few actionable components/buttons, which are functionalities most likely to be used in the pages' context.
Aesthetic-Usability Effect	The color and shape aspects of the design were chosen to be more visually comfortable and aesthetically pleasing to be perceived as more usable.
Von Restroff Effect	The most vital actionable target, e.g., the "Go" button, which starts the navigation, for a page is shaped and colored drastically differently from the rest of the page's components for it to be distinguishable.
Doherty Threshold	To maximize productivity, the system reacts to the user's input within 400 ms.
Law of Common Region	A group of related information is packaged within a border, e.g., the price, duration, and arrival time of the same route are placed on the same border. In contrast, the same set of information of another route is placed on a different, separate border.
Law of Proximity	Related elements are placed near each other, e.g., a list of transit timetables for a transit stop consists of termini, and the frequency of each terminus is placed directly under the terminus name.
Law of Uniform Connectedness	The route directions in the route details page comprise different modalities, e.g., walking and departing on a subway, between which is a line that shows the connection between adjacent modalities.

system, e.g., Google Maps and Apple Maps, not only to provide familiarity in the user's journey but also customize the visual design to be more appropriate for usage in public transit. Due to their more straightforward nature and fewer details needing to be discussed, the other two solution ideas with their corresponding system functionalities and requirements are listed in Table I, alongside the solution mentioned above idea translations. With regards to the system functionalities and requirements translated from the generated solution ideas, a holistic view of the proposed system can be generally visualized in the to-be system diagram (see Fig. 1). The system would allow the users to search for details of transit stops or nearby locations as their origin and destination stops, view the suggested routes via different modalities, and see the detailed information of the selected route before starting the turn-by-turn navigation system.

D. Prototype

In the *'prototype'* phase of design thinking, the existing heuristic UX and UI guidelines and human-computer interaction (HCI) principles were applied so that we could design and implement a user-centric system for our target users [16]. First, we started with a low-fidelity user interface in which the selected UX/UI guidelines were applied. Based on the findings from the early evaluation of these low-fidelity prototypes and high-fidelity prototypes of the system, we improved the system's design, which led to the high-fidelity prototype, integrating with executable features and functionalities. Table II below expands on how each heuristic and principle was applied to the prototype design [16].

low-fidelity and high-fidelity prototypes in Figma. The high-fidelity prototype was created immediately with the mentioned constraints. The first page on the system's user interface is the home page (see Fig. 5-left), which includes a list of nearby transit lines, their termini, and the corresponding wait time for each line. The page also comprises a search bar that lets the users navigate to the search page, where they can search for transit stops and nearby locations. The main component of the home page is the map, which shows the user's place in the center of the screen; it can be rescaled and panned to different areas using common gestures on the smartphone, i.e., pinching and dragging.

The second page that will be used extensively by the users is the search page (see Fig. 5-right). The search page consists of a search bar that accepts transit stop names and location names input from the user. After the user starts typing the location name, the system automatically suggests transit stops and locations with the same starting letters, where users can select to view details. The page that follows the search functionality is the stop details page (see Fig. 6 - left), where the user can see relevant information about the transit stop, including the stop name and the distance from the user's current location. The information card also includes information about transit connectivity, consisting of transit lines through the stop, next departure, and timetables. Users can navigate directly from their current location to the transit stop by tapping on the "*Go*" button. The page also shows an enlarged map of the transit stop on the top half of the page, where users can see a detailed view of the stop.

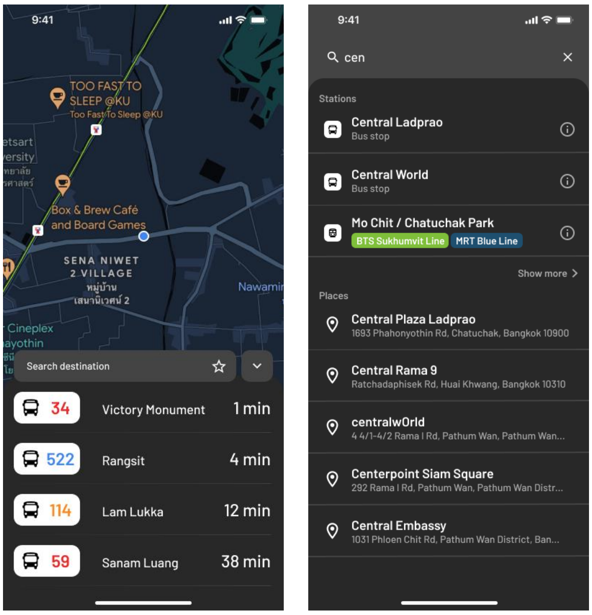


Fig. 5. Home Page (left) and Search Page (right)

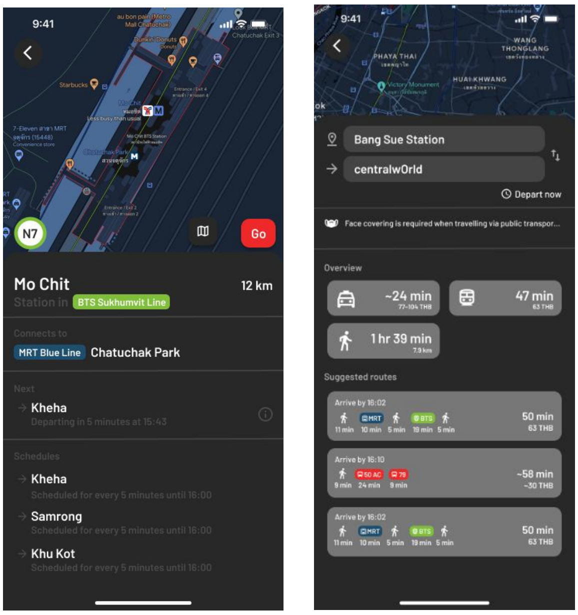


Fig. 6. Stop Details Page (left) and Route Selection Page (right)

Based on the system requirements and functionalities translated from solution ideas, a set of user interface prototypes was designed with regard to the UX/UI principles using Figma, including home, search, stop details, route selection, route details, and directions preview pages. However, the low-fidelity prototype was skipped due to the time limitation and the marginal effort gap between creating

Another essential page of the system where the large number of components could become challenging for the UI design is the route selection page. Users are shown the origin and destination on this page, with options to swap the choices and change the departure time. Users are prompted with a list of overviews of each route suggestion with the information for a time duration, arrival time, fare, and the order of transit modes from origin to destination. In addition, the system also shows a public health announcement to remind users when a face covering (e.g., surgical mask) is required (see Figure 6 – right). Lastly, the penultimate page of the system is the route Details page, which is followed by the actual navigation system. The route details page expands the information from the one shown on the route selection page (see Figure 7).

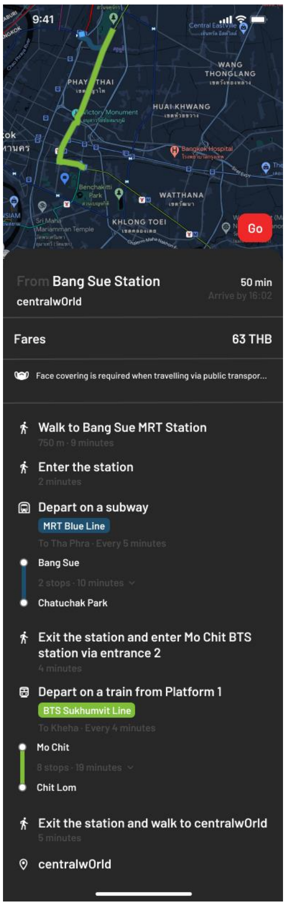


Fig. 7. Route Details Page

On top of the information already established, the page also shows, in detail, the step-by-step direction to accomplish the trip via the selected route, including but not limited to distance (walking only), time duration, transit frequency, and the transit line. The actual navigation page is not shown in this section as it had not been designed in of initial prototyping phase but was done after the early user evaluation. A functional prototype of the system was constructed on the tools and frameworks, including React Native (Expo) for the front-end, Node.js for the back end, Figma for prototyping, MySQL for database management, Git Version Control, GitHub for the remote repository, Amazon Web Service for Cloud server provider, and Google Maps API for navigation API respectively.

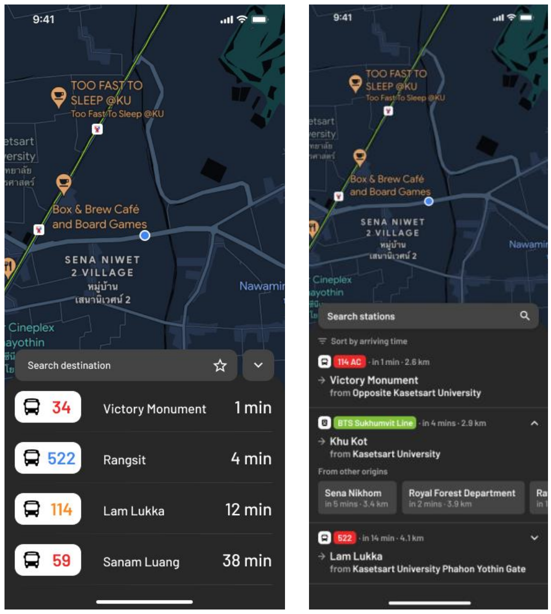


Fig. 8. Improvement of the home page UI prototype (from left to right)

TABLE III
EARLY USER EVALUATION PROTOCOL

Item	Duration
Introduction, informed consent, briefing	1 minute
Inspection: Home	30 seconds
Interview: Home	3 minutes
Inspection: Route Details	30 seconds
Interview: Route Details	3 minutes
Inspection: Route Selection	30 seconds
Interview: Route Selection	3 minutes
Interview: Overall design	3 minutes
Debriefing	30 seconds

E. Test

The design of the prototype underwent an early user evaluation. To compensate for the time limitation, the evaluation process was brief and contained only essential steps that would be valuable to the continuation of design improvement. The process involved 3 participants who assessed the design of three pages of the system: home, route details, and route selection. The procedures of the early user evaluation (see Table III) were estimated to last 15 minutes per participant. The evaluation process began with a short introduction to the project, consent information, and a briefing for the upcoming tasks. The participants were then prompted with the home page, and 30 seconds were allowed to inspect the design, followed by a 3-minute interview about the participants' attitudes toward the design. The inspect-interview loop was repeated for the route details and route selection pages before a 3-minute summative interview took place, where the participants gave suggestions about the overall design patterns. Finally, the evaluation ended after a 30-second debriefing.

The results from the 3 participants were primarily consistent with each other, mainly suggesting a review in choice of color, text size, and order of text placement. Improvements aside, the participants had positive attitudes toward the shapes, font, and map placement. Feedback from the early user evaluation was then applied to the prototype of the three pages used, and the improvements were extrapolated to the other pages where applicable. The home page received suggestions from users in a few areas. Firstly, the placement of the terminus name of each transit line caused some ambiguity to the users as they struggled to realize the purpose of the displayed characters. Secondly, the card on the bottom half of the screen was said to be too loose in information density; there was too much free space around the texts and symbols where more useful information could have fitted. To resolve the design flaws mentioned, the bottom card was redesigned entirely (see Fig. 8) to include more helpful information for each transit line. The texts were labeled appropriately to minimize ambiguity. While the route selection page had better reception during the early user evaluation, some elements could be improved according to the feedback.

Firstly, the public health announcement text could be better had the reader been entirely displayed at once without the marquee effect. Secondly, the text sizes for the time duration and fare of each transit mode under the Overview tab were disproportionate to the importance of the information they represent. However, users would prioritize the time information over foods, and the importance of the fares to them would not be as diminished from the Time as represented by the minuscule text size. Thirdly, the contrast between the text and the background blocks was inadequate across the bottom card's Overview and Suggested routes sections. The design improvements (see Fig. 8) were to display the public health information text in 2 lines instead of using marquee effect on only a few overflowing letters, to adjust the text sizes under the Overview section by enlarging the Fares information and slightly lessening the size of the time duration text. Furthermore, the background color of the blocks was darkened to increase its contrast against the text on top, which improves readability for the users. The third page evaluated by the users is the route details page, where minor design flaws were discovered. Firstly, a participant suggested that the Go button above the bottom card have a color that resembles an exit button. Secondly, the text showing time duration was too small, considering it is one of the most desirable pieces of information in the section. Thirdly, the placements of the origin and destination names should be swapped since users tend to look for the destination over the origin and read top-to-bottom, where the design contradicts. Lastly, the secondary text color was too dim on the dark background, which reduced readability.

To improve the design, some minor design changes were made (see Fig. 9). The Go button was recolored to bright blue, which still follows the von Restroff effect but without the resemblance of an exit button. An upward arrow symbol was also added to emphasize the button. The order of placement for the origin and destination was switched, and an arrow was added pointing toward the goal to symbolize the trip heading to such a location. The text size for time duration was increased, and the secondary text color was brightened against the dark background. Finally, vertical ellipses were added to

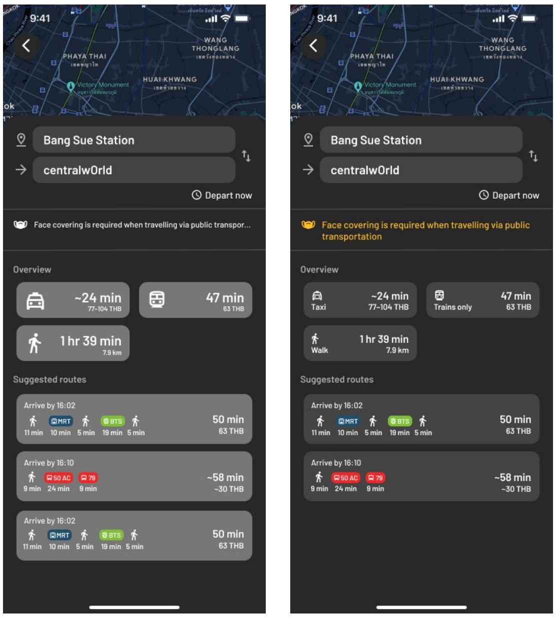


Fig. 9. Improvement of the route selection UI prototype (from left to right)

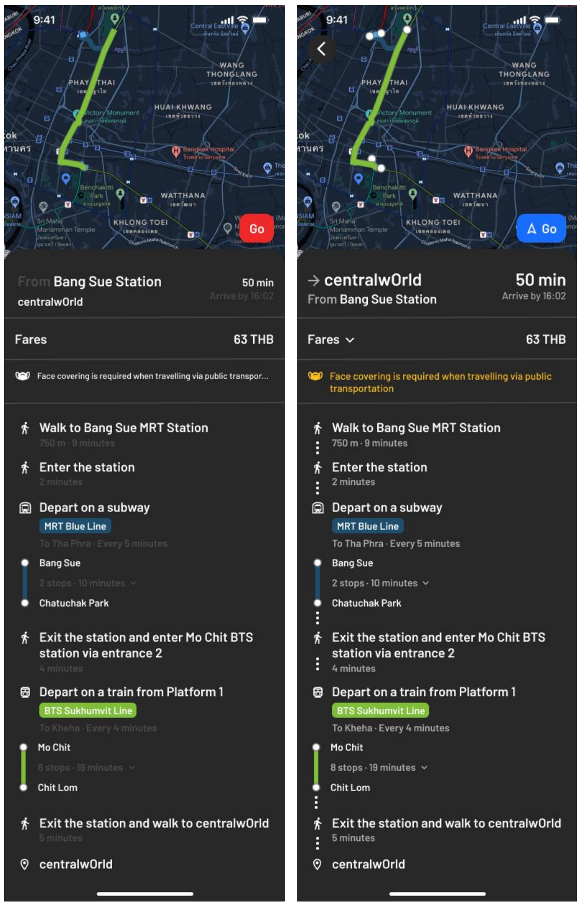


Fig. 10. Improvement of the route details page UI prototype (from left to right)

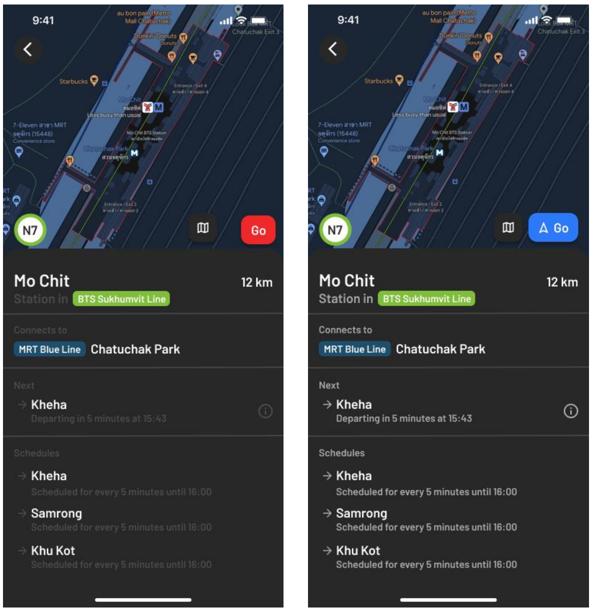


Fig. 11. Feedback extrapolation to the stop details page

the gaps between different transit modes to enhance usability following the Law of Uniform Connectedness. Marquee text was also removed from this page. In addition to improving the designs of the evaluated pages, some suggestions were considered for other prototype pages. For instance, the stop details page (see Fig. 11) had the same secondary text color and the same style of the Go button as the route details page (see Fig. 10)—with the feedback from the route details page, these two flaws were similarly fixed in the stop details page. Feedback extrapolation was applied across all functional prototype designs to maximize usability and reinforce similar designs across the system. Design prototypes, at this stage, were still subject to further improvements after usability testing. The procedural details and results will be discussed in IV, where users will evaluate the system's usability.

IV. Usability Testing

In a product development process, a usability evaluation is crucial in making the process and the product user-centric [17]. Alongside the design thinking principles, which is a user-centric development framework in itself, usability testing is one of the essential components of the study. The evaluation was carried out to assess the system's usability from the user's perspective, indicating how well the product could fulfill the users' needs [18]. This study conducted usability testing as each participant attempted to complete given tasks on the mobile application in a controlled setting. Participants were encouraged to think aloud during the process while being observed by a researcher, and a short interview was done after each task. A follow-up usability questionnaire then followed the studies. The table below (see Table IV) shows the usability testing protocol. The questionnaire used in the usability testing is the system usability scale (SUS), a nonproprietary measurement tool for the usability of a system that is considered simple, reliable, and versatile across different product categories [19]. The SUS is a 10-item questionnaire (see Table V) on a 5-point Likert scale on which the participants indicate their degrees of agreement or disagreement. The SUS can evaluate the system's overall usability from the user's perspective [20].

After each task completion, the participants were interviewed with two questions that let them point out particular features or components of the system that they had opinions about (see Table VI). The first interview question allowed the participants to indicate the features or details that they prefer and would appeal to them to use the system again in the future. This question aimed to identify the parts with the lowest priorities for fixing or redesigning, so the developers were informed not to make any drastic changes to these components yet. On the other hand, the second interview question asked the participants to indicate the features or details obstructing the flow of the system usage. This question aims to pinpoint the vital design issues of the system, which should be assigned the highest priorities for refinement or redesigning.

TABLE IV
Usability Testing Protocol

Item	Duration
Introduction, informed consent, briefing	1 minute
Task 1: Stop Details Usability	2 minutes
Task 1 Post-task Interview	1 minute
Task 2: Line Search Usability	2 minutes
Task 2 Post-task Interview	1 minute
Task 3: Navigation Usability	2 minutes
Task 3 Post-task Interview	1 minute
SUS and Debriefing	2 minutes

TABLE V
System Usability Scale Questions [20]

SUS1	I would like to use this system frequently.
SUS2	I found the system unnecessarily complex.
SUS3	I thought the system was easy to use.
SUS4	I think that I would need the support of a technical person to be able to use this system.
SUS5	I found the various functions in this system were well integrated.
SUS6	I thought there was too much inconsistency in this system.
SUS7	I imagine most people would learn to use this system very quickly.
SUS8	I found the system very cumbersome to use.
SUS9	I felt very confident using the system.
SUS10	I needed to learn many things before getting into this system.

TABLE VI
Post-task Usability Interview Questions

Interview Questions
Which parts of the system appeal to you to continue using it in the future?
Which parts of the system are stagnating the flow of usage to you?

In each task's procedure, the observing researcher took notes of the participants' thoughts and actions. The data of each participant's actions comprise the Time they spent on each task and the number of mistakes made along the way. A mistake is loosely defined as actions done by the participant that is unnecessary or would lead to other parts of the system that do not belong to the correct path toward the finishing line defined in Table VII.

TABLE VII
TASK DESCRIPTION

Task	Task Description	Finishing Line
1: Stop Details	Find the schedule frequency at N5 Ari	The user reaches the Schedules section under the stop details page of N5 Ari.
2: Line Search	Find the nearest Airport Rail Link station	The user reaches the stop details page of A8 Phaya Thai by searching under the Lines tab.
3: Navigation	Start navigation for a trip from Chamchuri 9 Building to RN08 Don Muang	The user reaches the turn-by-turn navigation page for a journey from the Current Location (Chamchuri 9 Building) to RN08 Don Muang

When starting a new task, the participant must always begin from the *Home* page. The process of navigating back to the *Home* page was not considered for the usability scoring, but suggestions for improvements were accepted (if any). The participants consisted of 10 people from the Chulalongkorn University Chorus Club since there are members of various participants were informed about the terms and conditions, and their consent was acquired before the testing. The personal information of each participant that could later identify the individuals is not recorded, and any other information is not kept for longer than specified in the terms to protect the privacy of all participants.

V. ANALYSIS AND RESULTS

Recruited participants were asked about their gender, level of education, age, and monthly income. The distribution of gender is 50% females to 50% males, and the period varies from 19 to 23 years old. The average monthly payment of the participants ranges from 0 to 50,000 baht. The results from the SUS were reported and translated into a meaningful score according to the procedures defined for the SUS [20]. For all ten questions in the questionnaire, the contribution score for each question ranges from 0 to 4, and there are different procedures for the event and the odd-numbered questions. Questions 1, 3, 5, 7, and 9 are scored by subtracting the user's response by 1, and questions 2, 4, 6, 8, and 10 are achieved by removing five from the user's response. Then, the sum of every question's contribution scores was multiplied by 2.5 to convert the score on a 0 – 40 scale to a score on a 0 – 100 scale. The entire procedure was repeated for every participant, and the average SUS score was calculated across all participants. After analyzing the responses from the SUS, the SUS score came out to be 77.5 out of 100 points. According to [21], a score of 77.5 lands on approximately the 82nd percentile on the SUS score distribution curve, where the average score is 68.

After each participant completes a task, the number of mistakes and the Time spent on the task were recorded. Those values were then converted into a usability score as a sum of contribution scores from both aspects. For the Time spent, the researcher had determined that each task given should ideally not take over 20 seconds; hence, a score of 5 was awarded for attempts that did not exceed 20 seconds. A deduction of 1 point from the time score was deducted for every 20 seconds spent over the first 20 seconds until the score reached 0. A 1-point penalty to the overall score was imposed if the attempt had taken 2 minutes or longer, where the attempt for the task is considered failed.

Meanwhile, the mistakes score has a maximum of 5 points, awarded to attempts with no mistakes made along the way. A 0.5-point penalty was imposed on the mistakes score for every error made. After three mistakes, the penalty increases to 1 point for every mistake made after the 3rd. From the observation of each participant's performance on completing the three tasks, it is consistent throughout all participants that the user interface was simple and intuitive to navigate through, partly because some participants were already familiar with the design of conventional mobile navigation applications such as Google Maps and Apple Maps.

However, the observer had noticed the system's flow was often obstructed by the need to double-tap on specific target components before correctly registering the gesture and the slightly small hitboxes for some buttons. Similarly, the post-task interview revealed that the participants were pleased with the overall placement of controls and components on the screen and the aesthetic aspects of the user interface design. The suggestions that the participants provided include increasing the sizes of some components' hitboxes, allowing the system to register gestures after only a single tap on the screen, and adding a brief introductory tour for the application's first start-up to showcase all unique features that might have been missed by new users. Lastly, the score for each task's completion, averaged across all participants, was translated from the observed Time spent and mistakes made. Using the scoring scheme defined in Tables IX and X, a total usability score of a task is the sum of scores from the two criteria, which combines to have a total score of 10. As a result, the total usability score of the three tasks averaged across all participants is 26.5 out of 30, which equals 88.3%. The averages of the recorded values and the converted scores are shown in Table XI.

TABLE VIII
SUS RESULTS

Item	Contribution Score (0–4)
SUS1	3.2
SUS2	3.1
SUS3	3.1
SUS4	3.0
SUS5	3.1
SUS6	3.2
SUS7	3.0
SUS8	3.1
SUS9	3.0
SUS10	3.1
Sum	**31.0**

TABLE IX
SCORING BY TIME CRITERION

Time Spent (minutes)	Score
2:00 or more, or task failure	-1
More than 1:40 but less than 2:00	0
More than 1:20 but less than 1:40	1
More than 1:00 but less than 1:20	2
More than 0:40 but less than 1:00	3
More than 0:20 but less than 0:40	4
0:20 or less	5
Full Score	**5**

TABLE X
SCORING BY MISTAKE CRITERION

Mistakes Made	Score
0	5.0
1	4.5
2	4.0
3	3.5
4	3.0
5	2.0
6	1.0
Seven or more	0.0
Full Score	**5.0**

TABLE XI
USABILITY TEST RESULTS AND SCORES

Task	Average Mistakes Count	Average Time Spent (seconds)	Average Usability Score
1: Stop Details	0.3	22.6	9.2
2: Line Search	0.9	33.6	8.5
3: Navigation	0.0	30.9	8.9
Total Usability Score			**26.5**

VI. DISCUSSION AND CONCLUSION

According to the results from the usability testing and users' feedback, the current system's design is excellently usable, partly due to thoroughly applying design principles and heuristics onto relevant components. Moreover, since the design of the mobile application had been evaluated once in the early user evaluation, most design flaws were eliminated from the early prototype. The SUS score at the 82nd percentile indicates that the system is well above average in terms of usability [21], and the usability score of 88.3% also agrees with the SUS score placement. From the usability score results in Table XI, the average Time spent on every task still exceeds the predetermined 20-second window. However, the Time spent for each use case will likely drastically reduce for non-first-time usage. In addition to fixing the double-tap issue, allowing users to personalize the application's layout could potentially drive the usability score higher [21].

Currently, the system can effectively solve the problems in the Bangkok public transit system by offering users information on the transit systems and real-time navigation across Bangkok via public transit. Having successfully designed and developed a functional system that solves the persisting issues of Bangkok public transit, the key takeaway from the study is the final design of the application pages themselves, which have been through multiple feedback loops via user evaluation sessions. Furthermore, the study also compiles the issues of Bangkok's public transit that are obstructive for public transit users. This study can only solve the problems that do not involve the government and official authorities. Some limitations to the system include the slight inaccuracy in the arrival and departure times, which is often caused by unexpected and unannounced delays from the transit operators. Nonetheless, the mobile application can outperform other existing systems, such as Google Maps, in terms of Time and price accuracy, which are the major concerns for users.

In conclusion, to design and develop a Bangkok public transit navigation system as a mobile application, the authors aimed to provide users with relevant and detailed information about traveling via various modes of public transit to reduce Time spent, redundancy, confusion, and burden. In contrast, the users plan for their itineraries. By applying the design thinking principles to the system's design and development processes, the authors have created a functional system with a design evaluated by users to be highly usable and visually appealing. In future studies, as the infrastructures of public transit in Bangkok improves and users' demand shifts, the system will require constant revision and refinement to stay up to date with the current issues faced by the public by iteratively traversing the feedback loops envisioned by the design thinking principles. The limitations of the study include the sample size of the usability testing and offline mode is currently unavailable. In this study, we sincerely thank Prof. Chotirat Ann Ratanamahatana (Faculty of Engineering, Chulalongkorn University) and International School of Engineering for funding this project. Also, we thank all participants for their generosity and support in this project.

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SCIENTIFIC ASSOCIATION FOR INFOCOMMUNICATIONS

Who we are

Founded in 1949, the Scientific Association for Infocommunications (formerly known as Scientific Society for Telecommunications) is a voluntary and autonomous professional society of engineers and economists, researchers and businessmen, managers and educational, regulatory and other professionals working in the fields of telecommunications, broadcasting, electronics, information and media technologies in Hungary.

Besides its 1000 individual members, the Scientific Association for Infocommunications (in Hungarian: Hírközlési és Informatikai Tudományos Egyesület, HTE) has more than 60 corporate members as well. Among them there are large companies and small-and-medium enterprises with industrial, trade, service-providing, research and development activities, as well as educational institutions and research centers.

HTE is a Sister Society of the Institute of Electrical and Electronics Engineers, Inc. (IEEE) and the IEEE Communications Society.

What we do

HTE has a broad range of activities that aim to promote the convergence of information and communication technologies and the deployment of synergic applications and services, to broaden the knowledge and skills of our members, to facilitate the exchange of ideas and experiences, as well as to integrate and harmonize the professional opinions and standpoints derived from various group interests and market dynamics.

To achieve these goals, we…

- contribute to the analysis of technical, economic, and social questions related to our field of competence, and forward the synthesized opinion of our experts to scientific, legislative, industrial and educational organizations and institutions;
- follow the national and international trends and results related to our field of competence, foster the professional and business relations between foreign and Hungarian companies and institutes;
- organize an extensive range of lectures, seminars, debates, conferences, exhibitions, company presentations, and club events in order to transfer and deploy scientific, technical and economic knowledge and skills;
- promote professional secondary and higher education and take active part in the development of professional education, teaching and training;
- establish and maintain relations with other domestic and foreign fellow associations, IEEE sister societies;
- award prizes for outstanding scientific, educational, managerial, commercial and/or societal activities and achievements in the fields of infocommunication.

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