Cognitive Cities: The Synthesis of Artificial Intelligence and The Urban Environment

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Introduction: Towards the Cognitive City

Digital transformation and the advancement of Artificial Intelligence (AI) are rapidly disrupting many facets of human life through emerging technologies, such as in computer vision, natural language processing, speech recognition, augmented and virtual reality (AR/VR), robotics and autonomous systems. COVID-19, while disrupting entire economies, has also propelled innovation in digital services for employment (remote working), health care (clinical networks), public transportation (self-driving cars), logistics (autonomous systems), and leisure (entertainment platforms) around the world, building upon technological megatrends of the last decades. However, despite this rapid progress, these technological advances have been randomly applied to the improvement of city living and of the human-digital user experience in urban spaces.

Traditional digital and smart city concepts still rely on retrofitting existing assets and services with smart technology (smart grids and sensors connected through IoT platforms), to overcome contemporary urban challenges and ageing legacy infrastructure (Townsend, 2012 and Picon, 2015). Smart city strategies, as pioneered by cities like Singapore, Seoul, London, Barcelona, or Helsinki, have recently demonstrated the promise of a more interconnected, data-driven, and optimized urban environment that promotes a better quality of life and liveability for its citizens (Eden Strategy Institute, 2021). However, specific behaviours and processes that both residents and visitors of cities can experience are often ambiguous, repetitive, or tedious, as they rely on isolated data silos that are not fully interconnected.

Additionally, the networks upon which smart cities are built are simply not yet fast, robust, or reactive enough to keep up with the world's evolving pace. While nascent 5G networks are already revolutionising the smart city environment, future 6G connectivity will truly lay the groundwork for ubiquitous wireless intelligence by 2030 (Latva-aho, Matti and Leppanen, Kari, 2019). Creating zero-latency urban environments where autonomous robots will be able to transmit and receive data without delay and where remote communication and collaboration will become instantaneous and immersive. Infrastructure, for example, can lead to seamless telepresence.

To respond to this unprecedented advancement of technology and its future integration into the design and management of cities, we must overcome traditional concepts of smart cities and enter the realm of synthetic urban intelligence to facilitate the evolution toward the cognitive city. The concept of cognitive city is influenced by the construct of "human intelligence," the uncanny ability of humans to connect and socialize dynamically, resulting in the exchange of information or knowledge. Evolving and expanding from the smart city concept with its more functional biases, the cognitive city promises to connect citizens to services more efficiently, increasing the cognition and "learning" of the city itself. Smart cities are fitted with

sensors to collect information from citizens and infrastructure that improves efficiency and cost of resources. A cognitive city, however, is more resilient, efficient, and sustainable, able to sense, understand, and respond to challenges in its environment, and to learn and adapt its behaviours, operations, and services based on analysis and contextualization of past experiences (Portmann and Fingers eds., 2016 and Portmann et al., 2019).

NEOM, a new region in northwest Saudi Arabia on the Red Sea, is building a first of a kind cognitive city from the ground up as a cornerstone of Saudi Vision 2030. In January 2021, NEOM announced THE LINE (fig.1), an innovative approach to urbanization, where world-class technology uses real-time data and intelligence to provide a higher quality of life and shorten the time from idea to viable business for enterprises (NEOM, 2021).

THE LINE is a 170km-long linear urban development model that improves liveability with full-realised three-dimensional urban design (fig.2). Through early deployment of robotics, human-machine symbiosis, AI, and augmented urban interfaces, THE LINE will ignite the growth and facilitate the adoption of leading-edge digital solutions. While smart cities around the

Figure 1: NEOM, THE LINE (source: NEOM)

world focus on retrofitting and connecting their assets to offer better quality of life and services, NEOM is in a position to build a truly cognitive city digitally from the ground up, one that will be predictive in nature and allow humans and machines to harmonize by design to create a new future. As a cognitive city, NEOM will sense, understand, and respond to urban challenges, learning and adapting operations based on analysis and contextualization of past experiences stored in vast pools of Big Data.

This article outlines the components of this synthesis between AI and the urban environment that underpins the concept of the cognitive city. This includes the design of a future-proofed urban development model where urban design and digital technology work together to foster innovation and address the critical challenges of our age, like climate change, social inclusion, and sustainable economic growth.

Artificial Intelligence and the Urban Environment

THE LINE reshapes the traditional concept of urban life, enabling NEOM to become an economic engine powered by 100% renewable energy, where cities and communities will be built around people, not cars, and connected by a seamless physical and digital infrastructure layer. NEOM is planned to be a home to more than 1 million people from all over the world. A living urban laboratory, powered by AI, the city will continuously learn predictively to make life easier for both residents and businesses. An estimated 90% of data will be harnessed at NEOM, augmenting infrastructure capabilities beyond the 1% typically available in existing smart cities.

The master planning work at NEOM is focused on the development and implementation of specific urban design innovations like:

- Multi-layered vertical structures merging live, work and play environments

- Self-sufficient modular neighborhoods with shared assets and services

- Walkable and safe communities connected through seamless mobility systems

- Cognitive technologies and automation to make people's life easier and more convenient

- Advanced urban systems and robotics to revolutionize connectivity, logistics and delivery

Synthetic Intelligence is a term that better represents a genuine form of AI based on cognitive, heuristic principles of learning from previous experience and adapting and improving over time. Applied to the city, Synthetic City Intelligence will help refine and build on urban innovation and adaptation, generating continuously new neural pathways for NEOM as the first truly cognitive city in the world. A deeper understanding of the application of this Synthetic City Intelligence will unleash advancements in

sustainable urban design that will measurably improve and evolve current smart technology and digital city strategies.

The urbanization of AI requires the development of a synthetic approach between technology and a specific urban intelligence. Urban AI has been defined as the ability of certain artifacts to acquire and make sense of information about the surrounding urban environment to act rationally according to pre-defined set of goals (Cugurullo, 2020). The operations of these city systems are intended to be autonomous, able to learn from experience and to make predictions that can optimize performance. The integration of robots and autonomous systems into urban spaces, including self-driving cars, delivery robots, drones, etc., are essential parts of this new urban ecosystem, their deployment already sparking disruption in urban spaces (Tiddi et al., 2020).

NEOM is actively pioneering the development of some of these human-machine applications interfaces within its urban fabric to establish a new foundation as the world's first cognitive city. Three core, synthetic principles enable the integration physical and digital infrastructure and the digital experience of residents and visitors in NEOM: bridging the public and the private domains; merging the physical and digital worlds; and mixing real-life with virtual reality experiences

Bridging the public and the private domains

The built environment is too often defined by the rigid definition of specific human activities being confined to the domains of public or private spaces. This subdivision has a lasting impact on human behaviour and liveability, restricting the innovative use of cities and urban spaces in the 21st century. Emerging digital technologies offer the opportunity to overcome these limitations and to re-imagine the spatial and symbolic boundaries of the built environment at the scale of the individual, the home, the neighborhood, the workplace, and the city, while reconsidering and safeguarding aspects of privacy, ownership, sustainability, and inclusion. Single-purpose buildings or public spaces are becoming more and more obsolete, while emerging technologies and advanced construction materials are enabling more modular, adaptable, and flexible urban structures.

New concepts which bridge the public and private domains to increase safety and well-being such as city-wide clinical networks are being considered. Dynamic, cognitive adaptation of the public rights of way strengthen human interactions, reduce congestion and CO_2 emissions, and enhance human health and mobility. In particular, the predictive public realm should support a high degree of resilience in the case of external shocks, including future pandemics. An advanced cognitive framework of data infrastructure is required to perform the synthesis between AI and the urban environment. To facilitate this innovation, the NEOM-wide Operative System (NEOS) is currently being developed as the cognitive foundation that fulfills NEOM's needs for data storage, analytics,

and future applications. NEOS is designed to support innovation emerging from residents and businesses, including future, un-imagined digital and cognitive experiences that will bridge public and private urban spaces.

Merging the physical and digital worlds

Merging the physical and digital worlds in urban design can improve liveability, encourage socialization, and foster connectedness. Social integration and community participation can be encouraged through enhanced physical and digital interactions within urban spaces.

NEOM is transforming the relationship between humans and machines, empowering a completely new and integrated approach to the built environment. As an essential part of urban design at NEOM, robots and autonomous systems are integrally master planned into the productivity and operation of THE LINE. Whether humanoid, wheeled, air or water-borne, the planned use of urban robots at NEOM are to facilitate easy and secure operations, mobility, and seamless interaction with humans.

Additional concepts such as “gamification” and the “playable city” must be considered during the urban design process to promote an active and healthy lifestyle (Active Digital Living) and to enhance the relationship between people and the urban environment. Liveability and active digital lifestyles and mindsets will be built around work, play and leisure for residents and visitors. Human-centered urbanism that revolves around work/life balance, interconnectedness, urban environment gamification, and active healthy lifestyles is a guiding NEOM principle and will harmonise the human experience between physical and digital spaces.

The digital experience of urban spaces must also facilitate new dimensions of communication and interaction between those physically present and those connecting remotely. Mixed-reality capabilities should be seamlessly embedded into all public and private spaces, becoming an intrinsic aspect of this convergence between the physical and the digital worlds for limitless collaboration, whether it be for work or for leisure.

Mixing real-life with virtual reality experiences

Designing and developing a new cognitive city provides a groundbreaking opportunity for the development of a 1-to-1 physical-to-digital urban representation of NEOM to support the convergence of physical reality with this new digital cognitive city in new and currently unthinkable ways. This region-wide digital twin model is currently being developed as part of NEOM Digital Master Plan.

Experientially, the digital twin will allow residents and visitors at NEOM to be able to interact, manipulate, and experience multiple, highly personalized virtual worlds as immersive as in the physical world. This opens the possibility to a fully new era for remote presence and interaction. Limitless experiences in gaming, entertainment,

exploration, education, and work thus become visible on the NEOM horizon. As unexpected combinations and connections were born from the Internet of 30 years ago, so too will new digital paradigms expand as the boundaries between real life and virtual reality become increasingly mixed.

Allowing people to focus on the environment and the task at hand versus the interface itself requires processes to interface with augmented and virtual reality that mimic the real world human behaviours from familiar computer or mobile interactions. Anchor points for virtual or augmented elements and holograms should be embedded into the entire physical environment. Multi-modal inputs and outputs, including text, speech or gestures must be optimized, so the need to touch screens, door handles and other objects in daily life is minimized by the responsiveness of urban interfaces. To achieve these goals, the technology should be humanized. This human-centric design should be the basis for the technology powering the augmented urban interfaces.

NEOM as a cognitive urban platform will unleash the power of Artificial Intelligence, Machine Learning and Big Data to analyze and transform everything and every place. This digital transformation will open new human possibilities, with new challenges that must be considered and addressed, and most importantly, provide new opportunities for prosperity, trust, transparency, privacy, ethics, and business.

Synthetic City Intelligence

NEOM will develop an advanced framework for data transparency, privacy, and consent, ensuring personal data ownership and protection. At the heart of this data collection and connectivity is the individual. While cognitive cities bring the power of data analytics to decision making in new, unique ways, respect for citizens' privacy is equally at the forefront.

NEOM's cognitive city data infrastructure will also understand and adapt to people's needs and allow residents and visitors to better understand usage patterns, energy consumption and transportation needs, and act when there are issues. Urban AI machine learning practices will provide better data that empowers communities to develop better strategies to become more resilient to climatic, economic and cultural uncertainties.

Advanced connectivity will be ubiquitous at NEOM, with 5G/6G, fibre, satellite, and wireless solutions offering low-latency connectivity with the ability to process high volumes of data with minimal delay, reducing or eliminating the digital divide. NEOM will also push the boundaries of neural networks, AI, quantum computing and supercomputing, building synthetic city intelligence across three pillars; connecting citizens and enterprises digitally to physical things, computing or analysing those interactions, and contextualising that connectivity to drive new decision-making.

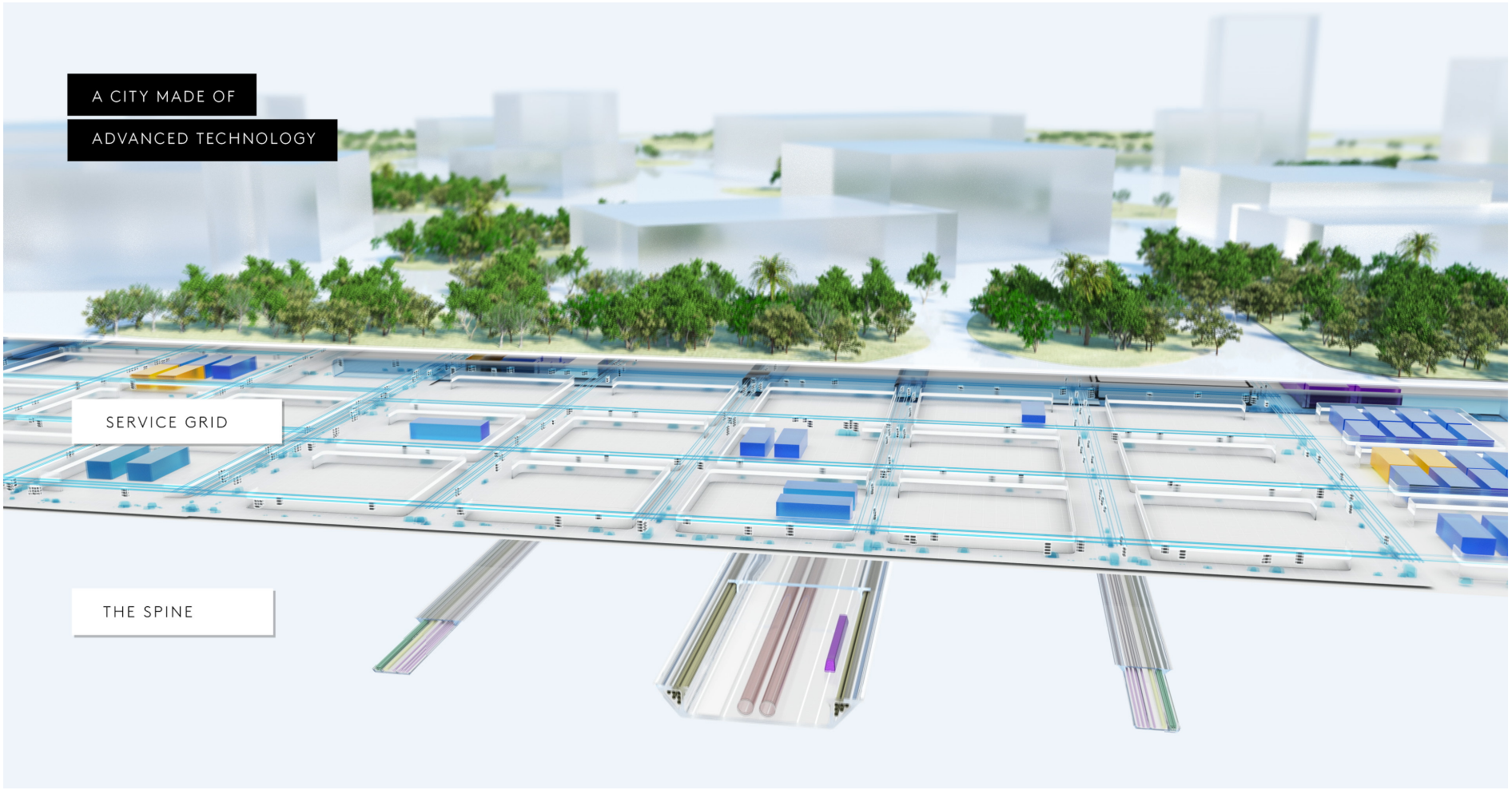

Figure 2. Illustrative three-dimensional urban design principles (source: NEOM)

Connecting citizens and enterprises digitally to physical things

Building a precise cognitive framework and processing language for the city so that it can learn about itself and exchange information among citizens and enterprises, and with other cities.

Computing and analysing urban interactions

Increasing computational capacity and Big Data processing with cloud, edge computing, and new, powerful data centers will allow NEOM to analyze these interactions.

Contextualising connectivity to drive new decision-making

Once processed, NEOM data will be contextualised and layered seamlessly into NEOM's cognitive infrastructure, to bring the power of data analytics to city life and decision-making through the development and commercialization of new urban tech applications.

NEOM ushers in the age of cognition to urban design to advance the promise of AI-powered Synthetic City Intelligence. Sensors, augmented interfaces, and other enabling digital technologies

will be embedded throughout the physical realm of NEOM by design, invisibly and seamlessly integrated into the urban environment. New approaches to urban design will include such features as adaptive urban furniture that can be digitally reconfigured, or dynamic street shading, lighting, or social distancing solutions. These technologies will also form the digital canvas on which completely new digital user experiences will be drawn, mixing the physical and digital domains through Augmented Reality (AR) and holographic overlays.

Through collaboration with a wide range of partners and stakeholders, NEOM plans to convene future research programs to expand the agenda on future cognitive city development. Synthetic Intelligence is a newer term that better represents a genuine form of AI based on cognitive, heuristic principles of learning from previous experiences and adapting and improving over time. Applied to urban design, Synthetic City Intelligence opens a new paradigm wherein urban innovation can be better planned into the design of the cognitive city, encouraging the growth of continuously new neural urban pathways. A deeper study, understanding and application of this Synthetic City Intelligence can unleash advancements in sustainable urban design that will measurably enhance and evolve current and future smart technology and digital city frameworks.

Biography

Mansoor Hanif is the Executive Director of Emerging Technology in the Technology & Digital sector at NEOM, where he oversees NEOM's initiatives on emerging technologies such as space, satellites, advanced robotics, and human-machine interfaces. He also leads the development of the NEOM Digital Masterplan and research collaborations with leading global universities and thinktanks. Previously, Mansoor spent over 25 years in the telecoms industry, most recently at EE and BT in the UK where he was Director of the Converged Networks Research Lab, and at Ofcom, the UK telecoms and media regulator, where he was CTO.

Joan-Anton Sanchez de Juan is Director Amenities & Public Services at NEOM Urban Development department, with more than twenty years' experience in the public and the private sectors specialising in the design and implementation of urban strategies within the fields of smart cities, urban innovation, and liveability. Trained as a geographer and anthropologist, he holds a PhD from the European University Institute in Florence. He was previously director of strategic analysis at the Mayor's Office, Barcelona City Council (2011-2015) and coordinator of strategic development policies at the President's Cabinet Office, Government of Catalonia (2001-2004). Author of several articles and essays on strategic planning, social innovation and urban governance.

Maysho Prashad is a Design Coordination Manager for The Line at NEOM. An accredited planner and trained architectural designer with over 16 years of

international experience gained in the United States, Asia, Middle East, and Africa. His expertise extends to upstream concept development and strategies, business development, client management, project management and delivery of large scale mixed-use, planning, urban design, and city development projects. He previously coordinated and supervised UN Habitat (United Nations Human Settlements Program) Riyadh Urban Lab for the Future Saudi Cities Program.

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