THE ETHICAL DIMENSIONS OF ICT IN THE DIGITAL TRANSFORMATION OF CITIES

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Abstract

This paper examines the ethical dimensions of integrating Information and Communication Technology (ICT), specifically digital twin technology, in the digital transformation of cities. As digital twins—enhanced by artificial intelligence for data analysis and decision-making—become increasingly prevalent in urban planning, it is crucial to address the ethical challenges they pose to ensure sustainable and inclusive urban development.

Using the UP2030 Project in Istanbul as a case study, the paper explores key ethical issues such as data privacy, security, and biases in AI models. A comprehensive ethical analysis is conducted alongside a multi-faceted methodology that includes a literature review, legal framework analysis, and an in-depth examination of project-specific documentation. The findings underscore the need for stringent data protection measures, equitable representation across demographic groups, and careful management of AI-driven decision-making systems to prevent the erosion of human oversight.

The paper argues that integrating AI-enhanced digital twin technology ethically into urban planning is essential for addressing energy consumption, climate resilience, and mobility challenges. Istanbul's case demonstrates how technology, when governed fairly, can drive positive change, achieving goals like carbon neutrality by 2050 while setting a global example. This approach not only ensures responsible urban development but also serves as a model for the sustainable and ethical evolution of smart cities worldwide.

Keywords: *Urbanization, Digital Twin, ICT, Ethical Considerations, Smart Cities, Istanbul, UP2030 Project*

1. INTRODUCTION

Urbanization is progressing at an unprecedented rate, with 68% of the world population expected to reside in urban areas by 2050. 95% of the urban expansion is expected to take place in the developing world, putting tremendous pressure on these regions to cope with the new human development challenges. (United Nations Department of Economic and Social Affairs, 2018) As cities are responsible for approximately 75% of global emissions, they are central to meeting the 2030 and 2050 emission reduction targets of the European Green Deal, set out to respond to the Paris Agreement. (United Nations Environment Programme, n.d.) The Mission for climate-neutral and smart cities calls for even faster action by cities to meet neutrality.

The current scenario requires cities to find ways to manage new challenges. Cities worldwide have started to look for solutions which enable high-quality urban services with long-term positive effects on the economy. (Pierce, et al., 2017) Many of the new approaches related to urban services have been based on harnessing technologies, including ICT helping to create what some call "smart cities." (Albino, et al., 2015)

The smart city is a growing phenomenon where the ultimate goal is to increase city resilience, sustainability and quality of life through smart innovations. (Pierce, et al., 2017) The smart city concept includes most technology-based innovations that tackle planning, development, operation, or management of urban activities. (Moggi & Dameri, 2021) Among other things, it can be utilized to catalyse efficient resource allocation, provide security, improve operational efficiency and facilitate human activities. (Mohammadi & Taylor, 2017) The idea is that vast amounts of data are being produced from the movement and behaviour of people and communities together with the infrastructure in highly connected cities. (Pierce, et al., 2017) This data can be utilized to maximize services (Mohammadi & Taylor, 2017) provided in the top layer of the city. (Pierce, et al., 2017)

1.1. Digital twin concept as part of thedigital transformation

Further technology that might contribute towards smart city goals is the digital twin. A digital twin is a digital representation of a physical asset based on timely data that allows for analysis, insight, decision-making, sense-making and interventions in the physical world. (El-Agamy, et al., 2024)

Digital twins involve developing technology, but also designing processes and tools that are run by people, enable collaboration, support human decision-makers and create positive outcomes for society. Digital twins scale up and improve through an ongoing cycle of prototyping, deployment and reflection. Digital twins bridge the physical world around us with a world of digital data and models, which represent the state of the asset, how it is performing and potentially predict its future state, enabling better interventions in the physical world. (El-Agamy, et al., 2024)

What distinguishes a digital twin from any other digital model is its connection to the physical twin. Based on data from the physical asset or system, a digital twin unlocks value principally by supporting improved decision-making, which creates the opportunity for positive feedback into the physical twin. (El-Agamy, et al., 2024)

1.2. UP2030 Digital Twins in Istanbul: A Use Case

Istanbul, a rapidly growing metropolis with a population nearing 16 million, faces significant urban challenges, particularly as it contends with the exacerbating effects of climate change. (UP2030 Project, n.d.) The city is increasingly susceptible to severe heat waves, which are intensified by the inefficiencies in the design and energy performance of its building stock, especially within economically disadvantaged neighborhoods. These inefficiencies contribute to elevated levels of energy consumption and greenhouse gas emissions. Furthermore, persistent issues such as traffic congestion and overcrowded public transportation systems strained Istanbul's urban mobility infrastructure. (UP2030 Project, n.d.) In response to these multifaceted challenges, Istanbul has committed to the C40 "Deadline 2020" initiative, which mandates a trajectory towards carbon neutrality by 2050. (IPA Istanbul, 2022)

As part of this commitment, the city participates in the UP2030 Project, which seeks to refine urban planning methodologies through the integration of advanced computational technologies. Central to this effort is the use of digital twin technology, which creates detailed virtual replicas of physical urban environments. These digital twins allow city planners to simulate, monitor, and optimize various aspects of urban infrastructure in real-time. The integration of artificial intelligence (AI) is crucial in enhancing the capabilities of these digital twins. AI algorithms, particularly those based on deep learning, process vast amounts of data collected from sensors and other sources to generate accurate predictions and insights. For instance, AI-driven models such as Recurrent Neural Networks, Graph Neural Networks, and Multi-layer Perceptrons are employed to forecast hourly energy consumption and electricity generation in buildings, as well as to analyse urban mobility patterns in targeted neighbourhoods (UP2030 Project, n.d.)

The UP2030 initiative prioritizes three key areas:

1. **Decarbonization of buildings and transport systems**: This includes the strategic integration of photovoltaic systems within both residential and public urban spaces.
2. **Sustainable transportation**: The initiative emphasizes the deployment of e-bikes powered entirely by renewable energy, ensuring that these solutions are accessible and equitable.
3. **Assessment of social impacts**: The project will rigorously evaluate the social benefits, particularly in reducing energy poverty and addressing health risks associated with extreme heat. (UP2030 Project, n.d.)

1.3. Ethical dimensions of the digital twin concept in Istanbul as a use case

The implementation of the digital twin presents substantial potential for addressing urban challenges, yet it simultaneously brings forth significant ethical considerations. (El-Agamy, et al., 2024) In the context of Istanbul's UP2030 Project, these ethical dimensions are salient. The application of digital twins to develop positive energy neighbourhoods and optimize urban mobility necessitates meticulous management to ensure data privacy and security. Given the city's diverse population and complex socio-economic landscape (Istanbul Development Agency, 2015), there exists a pronounced risk of bias and discrimination if the models fail to adequately represent all community segments. (El-Agamy, et al., 2024)

Crucial to the ethical deployment of the digital twin technology are considerations of accountability and transparency. While digital twins are sophisticated representations of the physical world, the decisions they inform are derived from complex data processing and predictive models that can influence real-world outcomes. This means that the algorithms and data used in digital twins must be transparent and the decision-making processes accountable to ensure that stakeholders trust the technology. (Helbing & Argota Sánchez-Vaquerizo, 2022) Clear documentation and communication regarding data collection, usage, protection, and decision-making processes are imperative for responsible and inclusive technology deployment. (Sanchez, et al., 2024)

Moreover, while digital twins are designed to reflect and manage the physical world, there is a risk that the insights and decisions they generate could be granted undue authority, potentially overriding human judgment. This can occur if stakeholders overly rely on the digital twin's recommendations without sufficient human oversight, leading to decisions that may be inaccurate, biased, or even vulnerable to manipulation or hacking. Such scenarios underscore a significant ethical challenge, as the technology could inadvertently prioritize its data-driven outputs over human values and nuanced decision-making. (Helbing & Argota Sánchez-Vaquerizo, 2022)

By proactively addressing these ethical dimensions, Istanbul can not only achieve its carbon-neutral objectives but also establish a benchmark for the responsible and inclusive implementation of digital twin technology in urban environments.

1.4. Thesis

This paper explores how the ethical integration of digital twin technology into urban planning can transform a city's approach to tackling energy consumption, climate resilience, and mobility challenges, using the UP2030 Project pilot city Istanbul as a use case. Addressing ethical concerns such as data privacy, bias prevention, and broader societal impacts is crucial for cities to benefit from digital twin technology. By focusing on these ethical dimensions, cities can pave the way for a sustainable and inclusive urban future.

Istanbul's case study shows how technology can drive positive change, underscoring the importance of ethical governance. Successfully implementing digital twins in Istanbul aims not only for carbon neutrality by 2050 but also to set a global example. This demonstrates that combining technological innovation with ethical considerations can build resilient and fair urban environments, serving as a model for the responsible and sustainable development of smart cities worldwide.

1.5. Research Gap and Contribution

While existing research extensively covers the technical aspects and potential benefits of digital twin technology in urban planning, there is a noticeable gap in addressing the ethical implications of its deployment. Most studies focus on the efficiency and performance improvements offered by digital twins, often overlooking critical ethical concerns such as data privacy, security, and bias in AI models. This study diverges from this trend by providing a comprehensive examination of these ethical dimensions, using the UP2030 Project in Istanbul as a case study. By doing so, it aims to fill the gap in the literature regarding the socio-ethical impacts of digital twin technology in urban settings. The research highlights the potential risks and proposes a framework for ethical integration, ensuring that the benefits of digital transformation are realized in a manner that is inclusive and sustainable. This focus on ethical considerations positions this study as a necessary complement to the predominantly technical discourse in the current body of research.

2. MATERIALS AND METHODS

2.1. Materials

The materials utilized in this study encompass a wide array of sources and documents, which are essential for a thorough examination of the ethical dimensions of digital twin technology in urban transformation. The key materials are as follows:

2.1.1. Scientific Literature

A thorough review of existing academic literature was conducted to gather theoretical insights and empirical data on digital twin technology, smart city concepts, and the ethical implications of ICT integration in urban environments. This literature review encompassed peer-reviewed journal articles, conference papers, and relevant books, which provided foundational knowledge and context for the study, particularly in relation to ethical concerns such as data privacy, security, and algorithmic bias.

2.1.2. Ethical Frameworks and Theoretical Sources

To specifically address the ethical dimensions of ICT and digital twin technologies, the study incorporated materials that provide ethical frameworks and theoretical perspectives relevant to these technologies. This included sources on applied ethics and international standards on ICT ethics. These materials were critical in forming the basis for the ethical analysis conducted in the study.

2.1.3. Legal Acts and Regulatory Documents

An analysis of pertinent legal frameworks and regulations was carried out to understand the compliance requirements and ethical guidelines governing data privacy, security and ethical deployment of AI systems and machine learning (ML) based technologies.

2.1.4. Project Documentation from UP2030

Detailed documentation from the UP2030 Project in Istanbul was critically analyzed. This included technical specifications, implementation strategies, and progress reports, which provided concrete examples of how digital twin technology was deployed in a real-world urban setting. These documents were not only used to understand the technical aspects but also to identify and assess ethical challenges specific to the project's implementation.

2.2. Methods

The methodology employed in this study was multifaceted, combining various analytical techniques to comprehensively address the research questions. The primary methods are detailed below:

2.2.1. Literature Review

An extensive review of scientific literature was conducted to build a theoretical framework for the study. This review involved systematic searches in academic databases using keywords related to digital twins, smart cities, data privacy, ethics, and ICT. The selected literature was critically appraised to identify prevailing theories, methodologies, and findings relevant to both the technical and ethical dimensions of the study's focus.

2.2.2. Ethical analysis

The study employed an ethical analysis methodology specifically to examine the ethical implications of digital twin technologies within the context of urban planning. This involved applying established ethical frameworks to the issues identified in the literature review and project documentation. The analysis focused on key ethical concerns such as data privacy, security, algorithmic bias, transparency, and accountability.

2.2.3. Legal Analysis

The legal analysis involved a detailed examination of EU regulations governing data privacy, security and ethical deployment of AI and ML-based technologies. Key legal documents such as the GDPR Regulation (EU) 2016/679 (GDPR), Regulation (EU) 2023/2854 (Data Act), Regulation (EU)

2024/1689 (AI Act) and international ICT standards were scrutinized to understand their implications for digital twin technology. This legal analysis was integrated with the ethical analysis to provide a comprehensive understanding of the regulatory and ethical landscape in which digital twins operate.

2.2.4. Case Study Approach

The UP2030 Project in Istanbul served as the primary case study for this research. A case study approach was chosen to provide an in-depth understanding of the implementation and ethical challenges of digital twin technology in a specific urban context. The case study involved a detailed analysis of project documentation. This approach facilitated a comprehensive examination of the practical and ethical dimensions of digital twin technology in urban planning.

2.2.5. Methodological limitations and mitigations

While this study employs a multifaceted methodology, including a literature review, ethical analysis, legal analysis, and a detailed case study, there are inherent limitations to these approaches.

One limitation is the reliance on existing project documentation and publicly available data, which may not capture all nuances and real-time developments of the UP2030 Project. To address this, efforts were made to cross-reference multiple sources of data to ensure a more comprehensive understanding.

Another limitation is the potential bias in literature and legal documents, which might reflect prevailing viewpoints rather than a balanced perspective. This was addressed by incorporating a diverse range of sources and critically evaluating contrasting viewpoints to ensure a thorough analysis.

Additionally, while the case study approach offers detailed contextual insights, its findings may not be universally applicable. This limitation is acknowledged, and recommendations for further research in different urban contexts are provided to enhance the generalizability of the study.

3. RESULTS

3.1. Understanding the digital twin technology specifications

Just a few years ago, creating digital twins of dynamic, possibly even living systems, would have been considered science fiction and deemed impossible from a scientific standpoint. (Helbing & Argota Sánchez-Vaquerizo, 2022) However, many believe that this scenario has recently changed and will continue to evolve, especially with the enormous amounts of data generated by the Internet of Things (IoT), transmitted via light (LiFi) or other low-latency communication systems, processed by quantum computers, and learned by powerful AI systems. (Helbing & Argota Sánchez-Vaquerizo, 2022)

To be precise, a digital twin consists of three crucial parts:

1. physical products
2. virtual products
3. the connections tying them

A digital twin fully describes a potential or physically manufactured product from the micro-atomic to the macrogeometrical level. Digital twin technology deeply integrates hardware, software, and IoT technologies to enrich and improve virtual entities. (Deng, et al., 2021)

3.2. Understanding the digital twin technology specification in Istanbul

The AI-powered toolset for the decarbonization of buildings and transport in Istanbul represents an advanced application of digital twin technology, designed to address the city's complex challenges related to energy consumption, climate resilience, and urban mobility. Digital twin technology serves as a sophisticated virtual representation of physical assets, such as buildings and transportation systems, continuously updated with real-time data collected from these environments. (Deng, et al., 2021) By integrating both physical and digital domains, this toolset not only aims to contribute to Istanbul's goal of achieving carbon neutrality by 2050 but also aspires to set a global standard for sustainable urban management. (UP2030 Project, 2023)

AI is integral to the functionality of digital twins, providing the analytical power necessary to translate raw data into actionable insights. While the digital twin offers a dynamic virtual model of the physical world, it is through AI that this model gains predictive and prescriptive capabilities. (Helbing & Argota Sánchez-Vaquerizo, 2022) AI algorithms, which process the continuous stream of data from IoT sensors and other inputs, are essential in modelling complex urban scenarios, forecasting energy needs, and optimizing infrastructure deployment (Lam & Wernholm, 2023).

In the context of Istanbul's UP2030 project, AI-driven models such as Recurrent Neural Networks (RNNs), Graph Neural Networks (GNNs), and Multi-layer Perceptrons (MLPs) are employed to accurately predict energy consumption, estimate renewable energy generation, and optimize the placement of critical infrastructure like photovoltaic (PV) systems and e-scooter charging stations. This symbiotic relationship between digital twin technology and AI enables a more responsive and adaptive approach to urban planning, where data-driven decisions can be made in real-time (UP2030 Project, 2024)

Stepping on the general methodology of describing the different parts of the digital twin technology solution such as: 1. physical products, 2. virtual products and 3. the connections tying them, the AI-powered toolset for the decarbonization of buildings and transport in Istanbul will be presented in the same manner. This approach will help in understanding the technology specifications, which is crucial for analyzing the ethical implications. (Deng, et al., 2021)

To understand the operation of this integrated technology, it is crucial to explore the three main components of the digital twin: physical products, virtual products, and the connections that unite them. (Deng, et al., 2021) This framework not only elucidates the technical specifications but also provides a foundation for analyzing the ethical implications of deploying such technology in a vibrant and diverse urban context like Istanbul.

3.2.1. Physical product

At the heart of this digital twin technology are the physical products, which in the case of the AI-powered toolset for the decarbonization of buildings and transport includes real-world buildings, PV and urban infrastructure such as e-scooter charging stations. These physical components are equipped with IoT sensors that collect real-time data on various parameters, such as energy consumption, environmental conditions, and mobility patterns. The physical products also encompass energy consumers like e-bikes and e-scooters, along with their charging stations, integrated into urban furniture to provide functionalities such as PV-supported charging and socializing areas.

3.2.2. Virtual product

The virtual product is the digital twin itself—an intricate 3D model that represents the physical urban environment in detail. (UP2030 Project, 2024) This virtual environment is where AI algorithms operate, running simulations and making predictions based on the data collected from the physical products. (Lam & Wernholm, 2023)

Tools such as Energy Plus, which models building energy consumption, and various AI-driven models like RNNs and GNNs, are utilized to simulate scenarios and optimize outcomes. For instance, the AI can forecast future energy demands based on predicted weather patterns or assess the potential for energy generation from PV systems under different conditions. This virtual component is essential for urban-scale modelling, enabling planners to visualize the impact of various interventions and make informed decisions that align with both sustainability goals and the well-being of residents. (UP2030 Project, 2024)

3.2.3. Connections tying them

The connections between the physical and virtual products are facilitated by robust data integration platforms and communication networks. These connections are the lifeblood of the digital twin, allowing for seamless data flow from the physical world to its digital counterpart and back. (UP2030 Project, 2024)

IoT communication protocols ensure that data from sensors is efficiently transferred to central data hubs, where AI algorithms process the information to update the digital twin in real-time. Cloud computing platforms play a vital role in storing and managing this vast amount of data, ensuring that the digital twin remains an accurate reflection of its physical counterpart. AI-driven analysis of this data enables continuous optimization of urban systems, such as adjusting energy distribution in response to real-time demand or refining mobility patterns to reduce congestion. By enabling such dynamic interactions between the physical and virtual domains, the digital twin and AI together create a feedback loop that enhances urban resilience and adaptability. (UP2030 Project, 2024)

3.2.4. Key Features

The AI-powered toolset for the decarbonisation of buildings and transport in Istanbul comprises four main modules, each designed to address specific aspects of urban decarbonisation.

- ***Module 1*** supports the calculation of climate change's impact on building energy use and occupant comfort for the years 2020 and 2050. It also explores different building energy retrofit options using deep learning approaches.
- ***Module 2*** automates the calculation of electric energy generated by rooftop solar panels, enabling efficient and accurate energy forecasting.
- ***Module 3*** helps users determine the optimal locations of PV-integrated e-scooter charging stations using existing travel data, enhancing the infrastructure for electric mobility.
- ***Module 4*** conducts feasibility analyses for the integration of real-time control of micro-e-mobility (e-bike and/or e-scooter) and PV electricity generation co-deployment, ensuring effective and sustainable energy management in urban settings.

These modules are interconnected through AI, which processes data from each component to ensure that the entire system functions cohesively and efficiently. (UP2030 Project, 2024)

3.2.5. Data requirements

The toolset's functionality is supported by comprehensive data collection and management.

- For ***Module 1*** "Building Energy Use and Retrofit Options", the required data includes geometric data such as building footprints, heights, and zone divisions; semantic data covering thermal transmittance of walls, roofs, and windows, window-to-wall ratios, number of occupants, boiler efficiency, infiltration rates, and more; and climate data involving dry bulb temperature, heating degree days, cooling degree days, and global horizontal radiation. (UP2030 Project, 2024)
- For ***Module 2*** "PV Energy Generation", the necessary data encompasses panel-related data including panel efficiency, area, age, tilt, and azimuth; shading data with annual shading information; and climate data such as average dry bulb temperature, heating degree days, cooling degree days, and global horizontal radiation. (UP2030 Project, 2024)
- ***Module 3*** "E-Mobility Charging Stations" requires building-related data including coordinates and electricity consumption of buildings; PV-related data such as electricity production from PV systems; and mobility-related data including the starting and ending points of e-scooter journeys. (UP2030 Project, 2024)
- For ***Module 4*** "Real-Time Control of Micro-E-Mobility and PV Electricity Generation Co-Deployment", the data requirements include several categories. Mobility-related data encompasses real-time location information of e-bikes and e-scooters, battery levels, and usage patterns. Energy-related data involves real-time energy production from PV systems, energy consumption rates of e-bikes and e-scooters, and grid energy availability. Environmental data includes real-time weather conditions that affect PV energy generation. Operational data consists of control algorithms for coordinating energy distribution between PV systems and e-mobility charging stations, as well as

real-time feedback on system performance and user demand. These data inputs are essential for optimizing the integration and real-time management of micro-e-mobility and PV electricity generation. (UP2030 Project, 2024)

3.2.6. Outputs of the toolset

The toolset provides various outputs to aid decision-making for carbon neutrality.

- ***Module 1*** calculates heating and cooling energy consumption, electrical energy consumption for lighting and equipment, and indoor overheating degrees, considering current conditions, retrofit scenarios, and climate change impacts for the years 2020 and 2050.
- ***Module 2*** determines the potential energy yield from installed PV systems on building rooftops, offering hourly, monthly, or annual resolutions.
- ***Module 3*** offers strategic placement of PV-powered e-mobility charging stations based on renewable energy availability and geographical distribution.
- ***Module 4*** provides feasibility analyses for the integration of real-time control of micro-e-mobility and PV electricity generation, outputting optimized control strategies for energy distribution and real-time performance metrics. (UP2030 Project, 2023)

Module	Function	Data Requirements	Outputs
Module 1	Energy Consumption and Retrofit Options	• Geometric Data: building footprints, heights, zone division • Semantic Data: thermal properties, occupancy rates • Climate Data: temperature, heating/cooling degree days, radiation	• Energy consumption calculations • Retrofit scenario assessments of climate change on energy use
Module 2	PV Energy Generation Calculation	• Panel-Related Data: efficiency, area, age, tilt, azimuth • Climate Data: temperature, radiation	PV energy yield predictions (hourly, monthly, annually)
Module 3	Optimal Placement of E-Scooter Charging Stations	• Building Data: coordinates, electricity consumption • PV Data: energy production • Mobility Data: start/end points of e-scooter journeys	Strategic placement of charging stations based on energy availability and geographical distribution
Module 4	Real-Time Control of Micro-E-Mobility and PV Electricity Integration	• Real-Time Mobility Data: location, battery levels, usage patterns • Energy Data: real-time PV production and consumption • Environmental Data: weather conditions	Feasibility and optimization of integrated energy and mobility systems

Fig. 1. Technical Specifications of the AI-Powered Toolset

3.2.7. Implementation and impact

Currently, there is no existing installation of this solution in Istanbul. However, a pilot area has been selected with the Istanbul Metropolitan Municipality (IMM) to design and install PV-integrated urban furniture that supports various functions. The solution's Technology Readiness Level (TRL) is currently at level 3, indicating that it is in the early stages of development and testing. (UP2030 Project, 2023)

As the project progresses, AI will continue to play a central role in refining the digital twin, ensuring that it evolves into a robust and responsive tool capable of supporting Istanbul's ambitious sustainability goals.

3.3. Key ethical considerations in digital twin technology through the lens of Istanbul's twin technology

The AI-powered toolset for the decarbonisation of buildings and transport in Istanbul represents a sophisticated application of digital twin technology. This toolset provides comprehensive urban-scale modelling, simulation, and machine learning-based calculations to address the city's pressing energy consumption challenges, climate resilience, and mobility. By integrating physical products, virtual products, and their connections, this technology enables the collection and analysis of extensive data to optimise energy usage, predict renewable energy generation, and enhance urban mobility. (Deng, et al., 2021)

However, while the benefits of this toolset are significant, its deployment raises key ethical considerations. These considerations are particularly critical given the specific technical specifications of the toolset, which involve detailed data collection from IoT sensors, advanced machine learning models, and robust data integration platforms. The primary ethical dimensions that arise include data privacy and security, potential bias and discrimination, and the implications for employment and societal well-being. (Deng, et al., 2021)

3.3.1. Data privacy and security ethical considerations

The AI-powered toolset for the decarbonisation of buildings and transport in Istanbul involves extensive data collection from IoT sensors installed on buildings, PV systems, and mobility patterns. This includes geometric and semantic data of buildings, weather information, and utilization data of e-bikes and e-scooters. (UP2030 Project, 2024) Given the sensitive nature of this data, ensuring its privacy and security is paramount.

The primary challenge lies in the sensitive data collection itself. The toolset gathers detailed information, including building footprints, heights, thermal properties, and occupancy rates, which are inherently sensitive and personal. Additionally, mobility data such as the start and end locations of e-bike and e-scooter journeys, times of use, and energy demand patterns contain personal information that requires stringent protection measures. (UP2030 Project, 2023)

Each module within the toolset presents unique challenges concerning data privacy and security due to the type and sensitivity of the data collected.

- ***Module 1*** gathers geometric data (building footprints, heights, zone divisions) and semantic data (thermal properties, occupancy rates). (UP2030 Project, 2024) The detailed nature of this information makes it inherently sensitive, as it can reveal personal and private details about building occupants.
- ***Module 2*** involves the collection of panel-related data (efficiency, area, age, tilt, azimuth), shading data, and climate data. (UP2030 Project, 2024) While less personal, this data requires protection due to its volume and the potential insights it can offer into energy consumption patterns and locations.
- ***Module 3*** collects mobility-related data, such as real-time locations of e-scooters and e-bikes, battery levels, and usage patterns. (UP2030 Project, 2024) This data is highly sensitive as it can trace the movements and habits of individuals, necessitating stringent protection measures.
- ***Module 4*** gathers real-time operational data for managing the integration of micro-e-mobility and PV electricity generation, including real-time location data, energy production, consumption rates, and control algorithms. (UP2030 Project, 2024) The real-time nature and operational sensitivity of this data make its security paramount.

Given the sensitive nature of the data the tool collects, which involves extensive data collection from IoT sensors, falls under the category of high-risk AI systems according to the AI Act. (The European Parliament and the Council of the European Union, 2024)

Establishing clear data governance policies is essential. (Edwards, 2015) These policies should define who can access, share, and use the data, ensuring that only authorized personnel handle sensitive information. Role-based access controls can further enhance data security by restricting access based on user roles and responsibilities. (OECD, 2023)

Ensuring that the vast amounts of data collected are securely stored and transmitted to prevent unauthorized access and breaches is critical. The use of cloud computing and IoT communication protocols introduces additional layers of complexity and potential vulnerabilities, necessitating advanced security measures. According to the NIS Directive, a legal act, which imposes the regulatory framework for ensuring the security of network and information systems in the EU, robust security protocols, including advanced encryption methods for data at rest and in transit, must be implemented to safeguard against unauthorized access. (The European Parliament and the Council, 2016) Advanced encryption methods for data at rest and in transit must be implemented to safeguard against unauthorized access. (El-Agamy, et al., 2024)

Addressing these challenges requires a multifaceted approach. Additionally, regular security audits and vulnerability assessments are necessary to identify and mitigate potential risks continually. These audits should be complemented by real-time monitoring and alert systems to detect and respond to potential security breaches promptly. (El-Agamy, et al., 2024)

Ensuring compliance with relevant data privacy protection regulations in the European Union – GDPR, Data Act, and Open Data Directive is critical for maintaining trust and legal compliance. In terms of data anonymization, privacy-preserving data analysis techniques should be employed to protect individual identities while maintaining data utility. (The European Parliament and the Council of the European Union, 2019) (The European Parliament and the Council of the European Union, 2023) (European Parliament and Council of the European Union, 2016) Methods such as data aggregation, pseudonymization, and differential privacy can help achieve this balance. (El-Agamy, et al., 2024)

3.3.2. The potential for bias and discrimination

The deployment of the AI-powered toolset for the decarbonisation of buildings and transport in Istanbul as a high-risk AI system raises concerns regarding bias and discrimination. One of the primary problems is algorithmic bias. The machine learning models utilized in the toolset, such as Recurrent Neural Networks (RNNs), Graph Neural Networks (GNNs), and Multi-layer Perceptions (MLPs), may inherit biases present in the training data. (UP2030 Project, 2024) This can lead to skewed predictions and decisions that unfairly disadvantage certain groups. (Brauneis & Goodman, 2018)

Relying on comprehensive data collection and advanced machine learning algorithms, is particularly susceptible to these risks. ***Module 1,*** which calculates energy consumption and retrofit options, depends on geometric and semantic data of buildings, potentially reflecting biases if certain building types or areas are underrepresented. (UP2030 Project, 2024) ***Module 2***, automating PV energy generation calculations, might produce biased outputs if the data does not accurately reflect diverse weather conditions and solar exposure across different neighbourhoods. (UP2030 Project, 2024) ***Module 3***, determining optimal locations for PV-integrated e-scooter charging stations, and ***Module 4***, conducting feasibility analyses for real-time control of micro-e-mobility and PV electricity generation, both rely on mobility and energy consumption data that may not represent all demographic groups equally. (UP2030 Project, 2024)

To mitigate these risks, it is essential to ensure that data collected for building energy consumption, PV energy generation, and mobility patterns is representative of all demographic groups. This involves gathering data from a diverse range of building types, geographical areas, and user profiles. By diversifying data sources, the toolset can produce more equitable and accurate predictions. (Lam & Wernholm, 2023)

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Additionally, representation is a critical issue. The data collected for the toolset may not adequately represent all demographic groups. This lack of representation can result in biased outcomes that disproportionately affect specific populations, potentially exacerbating existing inequalities. (The European Parliament and the Council of the European Union, 2024)

In this regard, measures should be taken to ensure that the AI system does not perpetuate or amplify biases, particularly those related to gender, ethnicity, or other protected characteristics. (Lam & Wernholm, 2023) Engaging a wide range of stakeholders, including underrepresented groups, during the development and testing phases can help identify and address potential biases early on. By involving diverse perspectives, the toolset can be designed and refined to be more equitable and inclusive. (Lam & Wernholm, 2023)

Implementing bias mitigation techniques is another crucial step. Techniques such as fairness constraints, re-weighting training samples, and regular model evaluations can help detect and correct biases in machine learning models. These methods ensure that the models' outputs are fair and do not perpetuate existing biases. (Lam & Wernholm, 2023)

3.3.3. The Implications of the Digital Twins on societal well-being

The AI-powered toolset for the decarbonization of buildings and transport in Istanbul is an advanced application of digital twin technology. This technology creates detailed virtual replicas of the city's physical infrastructure, which are used as platforms for running simulations and experiments. By integrating various technical features, including AI, the toolset enables the exploration and optimization of urban infrastructure and mobility solutions. (UP2030 Project, 2024) While proficient in data management and advanced analytics, the implementation of this toolset raises significant ethical implications concerning societal well-being. (Helbing & Argota Sánchez-Vaquerizo, 2022)

The extensive deployment of IoT sensors and the integration of various data sources across a large urban area like Istanbul increases the potential for significant adverse effects if the system fails or is misused. The use of AI in managing urban infrastructure and mobility patterns can significantly impact individuals' privacy, safety, and freedom of movement. (OECD, 2023)

One primary ethical concern is the potential for AI-driven decision-making within the digital twin environment to be accorded greater authority than human judgment. While the digital twin provides a comprehensive, data-driven model of the physical world, the decisions derived from AI algorithms may not always reflect the nuanced understanding that human decision-makers bring to complex urban environments. (Helbing & Argota Sánchez-Vaquerizo, 2022) This elevation of technology over human judgment can lead to several issues. For instance, the data-driven decisions made by the AI-powered toolset might not always reflect the nuanced understanding that human decision-makers bring to complex urban environments. As a result, the representations of individual will, and community needs could become inaccurate or biased. (Helbing & Argota Sánchez-Vaquerizo, 2022)

The toolset's proficiency in data management could lead to an over-reliance on its outputs, potentially sidelining human oversight and critical thinking. Automated decisions based on AI analyses might not always capture the full context or account for the dynamic nature of urban environments. This could result in decisions that are misaligned with the actual needs and preferences of the community, leading to societal dissatisfaction and a lack of trust in the technology. (Helbing & Argota Sánchez-Vaquerizo, 2022)

Different modules within the toolset contribute to these potential ethical concerns. For instance, ***Module 1***, which calculates energy consumption and retrofit options, might automate building upgrade decisions without considering the social and cultural importance of certain structures. ***Module 2***, responsible for calculating PV energy generation, could emphasize efficiency over equitable access to renewable energy. ***Module 3***, which identifies optimal locations for e-scooter charging stations, might inadvertently prioritize certain neighbourhoods, exacerbating existing social inequities. Finally, ***Module 4***, which manages the real-time control of micro-e-mobility and PV electricity generation, might optimize energy usage in ways that overlook the broader social implications of energy distribution and mobility access. (UP2030 Project, 2024)

These issues collectively underscore a significant ethical challenge to societal well-being. The implementation of the AI-powered toolset must be approached with caution, ensuring that human oversight remains integral to the decision-making process. Ethical considerations should guide the development and deployment of the toolset, with a focus on transparency, accountability, and inclusivity. (Lam & Wernholm, 2023)

Ethical Dimension	Challenges	Mitigation Strategies
Data Privacy and Security	• Extensive sensitive data collection • Risks of unauthorized access and data breaches	• Robust encryption • Regular security audits • Clear data governance policies
Bias and Discrimination	• Algorithmic bias from training data • Unequal representation of demographic groups	• Diverse and representative data collection • Bias mitigation techniques (fairness constraints, re-weighting)Inclusive stakeholder engagement
Societal Well-being	• Over-reliance on automated decision-making • Potential reduction in human oversight • Decisions misaligned with community needs	• Ensuring human involvement in decision-making • Maintaining transparency and accountability • Fostering inclusivity

Fig. 1. Ethical Implications of the AI-Powered Toolset

4. DISCUSSION

4.2. Introduction to Digital Twins and Ethical Considerations

4.2.1. Overview of digital twin technology and its applications in urban environments.

In the rapidly evolving landscape of urban technology, emerging AI tools have the potential to significantly affect urban planning and management. (Sanchez, et al., 2024) Considerable growth has been observed in areas like smart cities, the internet of things (IoT), and digital twins, contributing to the digitalization of urban environments. The emergence of various technologies including loT, Al and big data made it possible to collect, analyse and utilize various forms of data that had previously been overlooked. (PwC, n.d.)

At the heart of the concept of digitalization of the city through ICT are urban digital twins — virtual replicas of cities that enable urban planners and policymakers to simulate, analyze and optimize various aspects of urban life. (Sanchez, et al., 2024) A digital twin, in its simplest sense, is a linked virtual model of a physical object. By connecting the real-time data of the physical object or process into its digital representation – programmed with mathematical models, AI and pattern recognition to faithfully recreate its sibling – the digital twin comes to life. (PwC, n.d.) By harnessing real-time data, advanced analytics and AI, urban digital twins empower city planners to visualize the impact of proposed changes, test innovative solutions and implement data-driven strategies that improve city services, infrastructure and resource management. As a result, urban digital twins serve as a powerful tool in transforming the vision of smart cities into reality. (Dell Technologies, 2024)

4.2.2. Explanation of the importance of addressing ethical considerations when deploying digital twins in cities.

Stepping on the knowledge gathered from the Istanbul use case, the ethical issues related to data privacy, biases and discrimination and transparency and accountability associated with using digital twins in urban environments will be discussed in the following paragraphs. It is crucial to recognize that despite the vast potential of this technology, its implementation must be approached with careful consideration of the ethical implications to ensure responsible and equitable use.

4.3. Data Privacy and Security

4.3.1. Data privacy ethical considerations

As urban planners increasingly use AI for their planning analyses, potential ethical concerns begin to surface, with privacy being one of the most prominent. Privacy in urban planning encompasses the safeguarding of individuals' and groups' rights to control personal and group information, particularly within the context of urban spaces and their interactions with them. (Helbing & Argota Sánchez-Vaquerizo, 2022) It involves respecting the boundaries of personal and group space and ensuring that individual and group data are collected, stored, and used in a manner that respects their autonomy. With AI-driven planning analyses, vast amounts of data may be required for comprehensive insights. (Sanchez, et al., 2024)

The dependability and accuracy of a digital twin are contingent upon the integrity of the data it receives from the physical system. Any falsification or modification of this data can lead to inaccurate modelling and analysis, resulting in poor judgments.

At the same time, one of the most pronounced privacy concerns in AI-driven urban planning revolves around the extensive data collection necessary for analyses such as traffic analysis. (Helbing & Argota Sánchez-Vaquerizo, 2022) Urban planners gather data from various sources, including public records, sensor networks, social media, and mobile applications. These data might encompass information about residents, visitors, and users as well as customers' movements, transportation habits, and even their social interactions. Although high-resolution, disaggregated data are indispensable for comprehending urban dynamics, the data simultaneously pose potential issues related to surveillance and infringements on individual and group privacy. (Kitchin, 2016) Facial recognition has been shown to sometimes generate false identification for decision purposes such as arrest. Surveillance can violate individuals' privacy and freedom rights, especially if they are unaware that they are being watched, their activities are being recorded, or decisions are being made solely based on automated surveillance. Striking a balance between data collection for insightful analysis and respecting individuals' privacy and freedom rights becomes an ethical question for planners in these cases. (Xia, et al., 2023)

Moreover, digital twins are particularly vulnerable to cyberattacks that target data integrity, posing significant threats. (The Tech Robot, 2024) Given the potential sensitivity of the information involved, a breach can have severe repercussions on individuals' privacy and overall safety. Unauthorized access to data can lead to identity theft, stalking, or other malicious activities, profoundly harming the affected individuals. (Helbing & Argota Sánchez-Vaquerizo, 2022) Urban planners and planning organisations bear the ethical responsibility to institute strict data security measures that ensure the information collected remains confidential, inaccessible to unauthorized parties, and not misused. (Braun, et al., 2018)

Given these risks, it is essential to implement robust security measures to protect the integrity and confidentiality of the data used in digital twins. Ensuring data privacy and security is crucial to maintaining the reliability of digital twins and the systems they represent, thus supporting informed and accurate decision-making in urban management. (The Tech Robot, 2024)

4.3.2. Data privacy considerations mitigation

Mitigating the risks associated with data privacy and security in digital twin technology involves several strategic steps. These steps ensure that the integrity, confidentiality, and availability of data are maintained, thereby supporting the reliable functioning of digital twins. (OECD, 2023)

To mitigate privacy concerns, there are methods for de-identification and anonymization to eliminate personally identifiable information from data sets. However, it is essential to recognize that de-identification is not infallible, and there remains a risk of re-identification if sufficient information is available. (Lauradoux, et al., 2023) Moreover, with the rise of external data sources and increasingly sophisticated AI algorithms, the possibility of re-identification attacks becomes more substantial. Planning organizations will need to recognize the limitations of de-identification and commit to ongoing research and development efforts to enhance privacy protection methods. (Dell Technologies, 2024) In addition, adopting best practices for data anonymization can help reduce the risk of re-identification, thereby preserving individuals' privacy. (OECD, 2023) Equally important is upholding the data subject's right to be informed. This involves ensuring that individuals are aware of what data is being collected, the reasons behind its collection, and how it will be used. Promoting transparency in data processing helps to build public trust and clarifies how the data contributes to the broader objectives of urban planning. (OECD, 2023).

Security measures include encryption, access controls, periodic security audits, well-defined protocols for responding swiftly to data breaches, and institutional review boards. Not only is this an ethical imperative, but it is also a legal requirement in many jurisdictions. (Smallwood, 2019) Unauthorized access is a major concern, as digital twins often handle private and sensitive data, making them attractive targets for hackers. These unauthorized intrusions can be aimed at gaining control over the real system that the digital twin represents or stealing data for industrial espionage. (Dell Technologies, 2024) Additionally, the interconnected nature of digital twins makes them susceptible to ransomware and malware attacks. Such assaults can disrupt the normal operation of the digital twin or even cause the physical system to shut down. (The Tech Robot, 2024)

Implementing a robust data management plan is vital for protecting privacy and minimizing risks. (Lam & Wernholm, 2023) This process involves assigning specific roles to data engineers, analysts, stewards, and business analysts. Every dataset must comply with identity access management, data reaction, and residency criteria throughout its lifecycle. Tools that support these processes include data masking, redaction, encryption, differential privacy, and lifecycle management. Establishing frameworks and principles for secure, transparent, and high-quality data exchange is essential. (The Tech Robot, 2024) This involves determining whether the dataset is owned publicly or privately, understanding its licensing parameters, identifying which parts require confidentiality, devising methods for data generation if it is not available, and ensuring secure data transfer between systems. Profiling parameters also include assessing the sensitivity and criticality of each dataset to prioritize security measures accordingly. These measures ensure that data governance practices are aligned with organizational policies and regulatory requirements, promoting accountability and data integrity. (Sanchez, et al., 2024)

4.4. Biases and Discrimination

4.4.1. Biases and Discrimination Ethical Considerations

Digital twins utilize real-time data to provide forecasts and decision-making basis. (Batty, 2018) (Tzachor, et al., 2022) The essence of the digital twin, or virtual layer in a smart city is using data modelling and analytics to help prioritize activities in city planning. (Oti-Sarpong, et al., 2022)

The expanding extent to which algorithmic processes are being utilized makes its biases increasingly important to address. (Zou & Schiebinger, 2018) With AI, machine learning and other tools used in digital twins comes a risk of bias. A major driver of bias in AI is the training data. Most machine-learning tasks are trained on large, annotated data sets. (Zou & Schiebinger, 2018) (Tzachor, et al., 2022) Bias in AI can arise in various forms, frequently stemming from skewed data sets or assumptions embedded in algorithms. (Lam & Wernholm, 2023)

In addition, missing data, such as census undercount data or low public survey participation rates, lead to representation bias in AI systems, primarily because these systems rely on data to learn, make predictions, and inform decision-making processes. (Lam & Wernholm, 2023) When certain populations are undercounted or missing from the data set, the AI models developed using these incomplete data inherit these gaps, leading to skewed outputs. These biases can lead to unequal outcomes in urban development, disproportionately affecting certain communities or failing to adequately represent the diverse needs of urban and other populations. (Lam & Wernholm, 2023)

4.4.2. Biases and Discrimination Considerations Mitigation

The challenge, therefore, is to ensure that AI systems in urban planning are developed and implemented with an awareness of potential biases. (Sanchez, et al., 2024) This involves not only scrutiny of the data used to train these systems, such as large language models (LLMs) and other generative AI applications but also continuous monitoring and adjustment of algorithms to address biases and outcomes as they emerge. (Lam & Wernholm, 2023)

Engagement and consultation with diverse community groups and stakeholders to understand their unique needs and perspectives can also inform more equitable AI development. Overcoming, reducing, eliminating, and ameliorating biases and their adverse effects on people is very difficult. Algorithms are susceptible to bias in several ways, even when sensitive factors like gender, ethnicity, or sexual orientation are accounted for. (Lam & Wernholm, 2023) It can be extremely difficult to account for and correct for non-merit factors. Even large amounts of accumulated training data can be incomplete or inaccurate, reflecting previous poor decisions, social conditions, the vestiges of past discrimination, and biased analyses resulting from historical conditions. Whereas software systems can be programmed to follow the rules of formal logic, assumptions and premises must be ascertained and examined for veracity and credibility, for which there are few resources or applications. (Sanchez, et al., 2024)

There are some basic steps to address potential ethical concerns relating to bias. Planners should keep up to date on the ethical dimensions of rapidly evolving urban technologies, including AI, which are being continuously uncovered as more and more applications are being implemented. (Sanchez, et al., 2024) In addition, planners can create accountable procedures that help reduce prejudice when they use AI, including the use of technical tools or operational techniques such as oversight committees or external evaluations. Much depends on who is doing the oversight and evaluation and whether the findings of the oversight group are adopted or merely treated as recommendations. (Sanchez, et al., 2024) Ongoing organizational discussions about potential biases in all plans or analyses can increase awareness to determine whether decisions are fair. Research has been conducted on how to hold individuals to higher standards using more sophisticated techniques for checking for bias in machines. (Lam & Wernholm, 2023) This can include comparing the outcomes of algorithm performance with human decisions and using explain-ability approaches that, depending on the AI technique used and the level of detail needed, can help identify factors that influenced the model's results. (Lam & Wernholm, 2023)

4.5. Transparency and Accountability

4.5.1. Transparency and Accountability Ethical Considerations

The issue of accountability is paramount for urban planners, regardless of the methods employed. AI systems introduce a layer of complexity due to the vast amounts and diverse types of data utilized. (Deng, et al., 2021) When these AI-driven decisions result in unanticipated outcomes, determining responsibility becomes challenging. Is it the responsibility of the AI developers, the data providers, the urban planners who implemented it, or the political leadership? This ambiguity can result in lack of accountability. For instance, if an AI system recommends reducing public transportation in certain areas, leading to decreased accessibility for lower-income residents, it becomes difficult to assign fault. Such ambiguity can exacerbate social inequalities. (Deng, et al., 2021)

The complexity of AI algorithms further complicates accountability. AI models, particularly those based on machine learning, are often described as black boxes due to their opaque analytical processes. This opacity makes it difficult for planners and stakeholders to comprehend how specific predictions or decisions are formulated. In urban planning, where decisions have far-reaching impacts on community development, infrastructure, and public welfare, this lack of understanding poses significant concerns regarding the equitable distribution of services and benefits. (Deng, et al., 2021)

Transparency is intrinsically linked to accountability. For urban planners to be held accountable, the processes and rationale behind AI-driven decisions must be transparent. However, achieving transparency in AI systems presents challenges. Many AI algorithms are proprietary, with their internal workings closely guarded by the developing companies. Even when algorithms are open for inspection, their complexity can render them incomprehensible to those without specialized knowledge. (Deng, et al., 2021)

Moreover, AI-driven planning tools can be prohibitively expensive and require specialized expertise to operate, potentially centralizing decision-making power among those with access to these resources. This centralization risks creating a less inclusive planning process, marginalizing community members and smaller stakeholders from decisions that directly impact them. (Deng, et al., 2021)

4.5.2. Transparency and Accountability Ethical Considerations

To address these issues, urban planners and planning organizations will need a multifaceted approach. One critical step is the development and enforcement of ethical guidelines for AI use in urban planning. These guidelines should emphasize accountability, requiring clear lines of responsibility for decisions made with the assistance of AI. (Deng, et al., 2021) They should also promote transparency, in terms of both the algorithms used and the data they operate on. Making these aspects of AI systems accessible and understandable to non-experts can help build trust and facilitate more inclusive decision-making processes. (Sanchez, et al., 2024)

Addressing these concerns requires a concerted effort from all stakeholders involved in the urban planning process. By developing ethical guidelines, promoting transparency, ensuring accountability, and engaging with the community, urban planners can use new AI methods while mitigating its potential ethical pitfalls. (OECD, 2023) However, it is important to point out that this is true for all aspects of a planner's responsibilities and is not limited to AI-based approaches. (Deng, et al., 2021) The use of AI algorithms in urban planning may be opaque, making it challenging for residents to understand how certain recommendations or decisions are made. A lack of transparency can erode trust in the planning process, particularly among marginalized communities that may already have a history of being excluded from decision-making. To address this concern, planners and organizations should prioritize transparency in their use of AI. Transparency should be emphasized throughout the planning process. (OECD, 2023)This means not only providing clear explanations of how algorithms work but also involving the community in algorithm development and decision-making. (Sanchez, et al., 2024)

4.6. Impact on general societal well-being

4.6.1. Ethical considerations regarding societal well-being

The combination of digital twin technology and artificial intelligence (AI) introduces significant ethical considerations, particularly concerning the balance between automated decision-making and human judgment. Digital twins serve as detailed virtual representations of physical entities—such as buildings, infrastructure, or even entire cities. When AI is applied to these digital twins, it enhances their functionality by analyzing vast amounts of data to simulate scenarios, predict outcomes, and suggest optimized solutions. However, this efficiency poses the risk of these AI-enhanced digital twins being granted greater authority than human decision-makers. ((Helbing & Argota Sánchez-Vaquerizo, 2022)

One key concern is that the data-driven insights produced by AI within a digital twin might not fully capture the complexity of human intentions and social dynamics. This can result in decisions that, while technically sound, fail to align with the nuanced needs and values of individuals or communities. For instance, if there is a discrepancy between a person's true intentions and the data represented by their digital twin, the system may prioritize the digital twin's data, potentially overlooking the individual's actual perspective. (Deng, et al., 2021) A societal digital twin could also be used to gauge how much pressure can be applied to individuals without provoking a revolution or to devise strategies to subdue majorities, undermine individual will, and impose policies misaligned with public sentiment. Such uses of mass surveillance would be highly invasive and undermine human rights. (Helbing & Argota Sánchez-Vaquerizo, 2022)

Even in less extreme scenarios, the increasing reliance on AI and digital twins for managing societal functions could result in the inappropriate application of methodologies better suited for corporate or logistical operations. These approaches may oversimplify complex human factors, treating critical aspects such as dignity and freedom as secondary concerns or "noise." This could erode the very strengths that allow societies to thrive—such as their capacity for adaptation, self-organization, and innovation. If left unchecked, these developments could lead to inhumane social structures, with the potential for a form of "technological totalitarianism," where control is prioritized over human welfare (Helbing & Argota Sánchez-Vaquerizo, 2022)

4.6.2. Ethical considerations regarding societal well-being mitigation

To address these ethical challenges, it is recommended that rather than substituting individual decisions with automated machine determinations, digital assistance should be utilized to support decision-making processes. This approach would provide individuals and systems with beneficial opportunities. Instead of seeking a single optimal solution for a given objective (e.g., selecting the shortest route), decision-support systems should offer multiple high-performance solutions, each characterized by diverse qualities pertinent to various goals. (Xia, et al., 2023)

Societal governance should prioritize human welfare. As individuals become increasingly integrated into socio-technical systems, it is evident that a purely technology-driven approach is insufficient. Social innovation is paramount to unlocking the full benefits of the digital age for all. A platform supporting genuine informational self-determination is urgently needed. Additionally, the traditional "war room" approach must be supplanted by a "peace room" approach, necessitating an interdisciplinary, ethical, and multi-perspective methodology. (Deng, et al., 2021) This new multi-stakeholder approach is essential for achieving better insights and fostering participatory resilience.

By ensuring that digital twins serve as tools to aid human decision-making rather than replace it, and by fostering environments where diverse perspectives are considered and respected, the potential for technological totalitarianism can be mitigated. (Deng, et al., 2021) This approach emphasizes the importance of transparency, accountability, and inclusivity in the deployment of digital twin technologies, ultimately supporting a more humane and equitable society. (Helbing & Argota Sánchez-Vaquerizo, 2022)

5. CONCLUSIONS

This paper explores the transformative potential of ethically integrating digital twin technology into urban planning, using Istanbul's UP2030 Project as a case study. The AI-powered toolset for decarbonizing buildings and transport addresses critical challenges in energy consumption, climate resilience, and mobility. To fully leverage the benefits of digital twin technology, it is essential to address ethical concerns such as data privacy, bias prevention, and broader societal impacts.

Ensuring data privacy and security is crucial due to extensive data collection from IoT sensors and AI systems. Robust security measures, such as encryption and regular audits, are essential. Additionally, addressing bias and discrimination is critical, as machine learning models can inherit biases from training data. This requires diverse data collection, bias mitigation techniques, and stakeholder engagement.

The reliance on automated decision-making systems raises concerns about diminishing human oversight. Ensuring transparency, accountability, and maintaining human involvement in decision-making processes is vital. By addressing these ethical considerations, Istanbul aims to achieve carbon neutrality by 2050 and set a global benchmark for ethical digital twin implementation. This approach demonstrates that combining technological innovation with ethical governance can create resilient and equitable urban environments, serving as a model for sustainable smart city development worldwide.

Looking ahead, the future of ICT in urban transformation, driven by AI, ML, IoT, and data analytics, holds immense promise. However, the ethical integration of these technologies is of absolute importance. Ensuring that advancements are inclusive, equitable, and transparent will be essential to embrace their full potential for urban improvement. Lessons from Istanbul's implementation can guide future projects, ensuring technological progress aligns with ethical responsibility.

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