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Implications of AI for Urban Sustainability

1. Introduction

In an era of rapid urbanization, urban sustainability emerges as a crucial framework for fostering resilient and livable cities. The formal definition of urban sustainability as defined by Diversity for Social Impact is “Urban planning actions and guiding principles to improve and build our cities without actively using our resources forever” (Man). However, most of these frameworks are riddled with flaws that limit the capability for expansion while keeping the same level of sustainability. This paper will explore these flaws within many of the top urban sustainability frameworks, while providing a solution to these issues, backed by solid evidence and data.

2. Problems with Traditional Models of Sustainability

Many efforts are being made to create models of urban sustainability to support the millions of people living in urban areas. It is estimated that around 2.5 billion more people will live in urban areas globally by 2050, showing the need for better and more scalable sustainability systems (Intelligence). Although the top global models of urban sustainability can keep up with the population’s needs, it is not feasible going forward with the exponential amount of people moving to urban centers.

2.1 Current Models of Urban Sustainability

Statistics and evidence collected over the years of research and studies show that the current sustainability models have many flaws that they fail to acknowledge. An analysis conducted in 2023 by the Next Generation Cities Institute identified issues with the top global frameworks of urban sustainability. It was argued that many of these frameworks, and cities across the globe fail to consider every aspect of urban sustainability and rather focus on a few that are considered important. Additionally, it is asserted that another issue relies on data collection methods, and each one needs to account for the negative impacts of their methods environmentally, economically, and socially. It is concluded from initial analysis that, “[they] see that most of them are focused on environmental and societal aspects. Economy and governance appear in a second group of important factors in some of them, and culture has lesser importance in most of the frameworks” (Gavaldà et al.). The evidence presents patterns between each of the top frameworks, and even the relatively balanced ones between the factors strongly emphasize the factors listed above. It is also important to note that many cities use machine learning and artificial intelligence to facilitate their frameworks. However, the use of AI & ML also presents issues with the methods of data collection employed. The paper claims that “However, as mentioned in Gap 3, we must assume those tools are only based on existing information. In that case, they cannot show the potential for societal change” (Gavaldà et al.). Data collection is a large factor in deciding how well the Artificial Intelligence model performs. By using past data the models are ineffectively predicting what will happen in the future, but attempt to predict using past trends. Instead, it is more efficient to use models that represent the cities more physically, such as with Digital Twin, which will be explored in later sections. It is also mentioned how many of these frameworks collect too much data, called an oversaturation of data. This is an issue because too much data can lead to “overfitting” the data, which again, ties

into the previous point of being unable to predict future trends accurately as the model tries to match the data rather than make predictions closely. The lack of proper data collection also shows how these frameworks are not sustainable and scalable for the future. To further back these claims up, the paper also states that, “There is a substantial difference between metrics, evaluations, and shared values. We can confidently say that one scenario has less CO₂ consumption than the other, but we cannot conclude that this scenario is better” (Gavaldà et al.). The example highlighted exposes a key flaw in urban planning. A lot of urban planners are only taking into account singular factors, ignoring dependant factors that also play a huge role in their desired result. The issues with the current frameworks of urban sustainability are not limited to machine learning and systems, but also models that place a high value on environmental sustainability fail to consider the damage done by construction and building operations. Construction in the EU accounts for around 39% of global greenhouse gas emissions (U.N. Environment). With the vast amount of construction ongoing globally, this percentage may continue to rise unless new methods of employing urban sustainability are found. Energy inefficient processes such as construction must be addressed in newer models of urban sustainability, or the world will not be able to scale to the exponential growth of population in urban centers.

3. AI for Urban Sustainability

Although the current frameworks and methodologies urban areas incorporate to reinforce sustainability have several aspects that could be improved, there are improvements or better models that can be made to fill in the gaps these models have. New developments in AI and Machine Learning may be what the frameworks need to be scalable and sustainable for the future. Even though many of the models discussed in the previous section incorporate some sort

of artificial intelligence or machine learning algorithms to aid their sustainability, with new technologies and better methods of data collection those issues can be suppressed. One such model is Digital Twin, which has been used globally in both a corporate setting and an urban setting. The key advantages & uses of this technology will be highlighted below.

3.1 Digital Twin

Digital Twin is a relatively new concept being used globally to boost efficiency for several different kinds of businesses and models. The formal definition of a Digital Twin as described by the Digital Twin Consortium is “a virtual representation of real-world entities and processes, synchronized at a specified frequency and fidelity” (Digital Twin Consortium). In other words, a Digital Twin represents a real-world process or entity, synchronized using real-time data from the given process. Places where Digital Twins is used include factories, healthcare facilities, product design & testing, and more. They are generally used to optimize results by adjusting factors. The fact that the simulation runs on current data and shows a simulation or model of what would happen given certain changes makes Digital Twin a viable option for many businesses worldwide. Physical prototypes are no longer needed with this new technology. For instance, NVIDIA has developed a framework named “NVIDIA Omniverse,” used by many top companies to create Digital Twins tailored to their needs. One of these companies, Wistron, a “leading global technology service provider” (McKenna), uses the NVIDIA Omniverse model to boost efficiency and quality. James McKenna in “What Is a Virtual Factory, and How They’re Making Industrial Digitalization a Reality” claims that Winston “has achieved a 51% boost in worker efficiency and 50% reduction in production process times” (McKenna). This evidence, along with the several other companies using the NVIDIA Omniverse framework which have benefitted greatly goes to show the power of Digital Twin.

This technology is something that urbanized spaces can embrace to boost efficiency, reduce costs, and improve the livability of these spaces.

3.2 Practical Applications of Digital Twins

As mentioned above, Digital Twin can be used in several aspects of factories, healthcare, and more. There are also several practical applications for Digital Twins in an urban setting. Some of these include urban planning, waste management, energy management, etc. Six key practical applications have been identified through research on the technology.

3.2.1 Climate Change & Environmental Issues

Digital Twin can be used by urban developers to see how a new building plan can affect a city's resources, pollution, and several other factors. As mentioned in a previous section, construction and building operations are some of the fields that cause the most climate change, and Digital Twin is a very effective solution to solve that problem.

Learning which methods of waste management work better for the environment is key to environmental sustainability in urban areas. Creating a virtual representation of the current waste management systems that these urban centers employ, will simplify the process of testing changes and how they affect other factors such as pollution, air quality, and more, which would otherwise be difficult to test by making real changes to the physical processes.

3.2.2 Economical Issues

Energy management is not only an issue that affects a city on an economic scale but also on an environmental scale. Cities must control energy usage (eg. light pole regulations) for maximum efficiency and usage. At the same time, using too much energy will also have long-term effects on the environment because of the production of electricity. Hence, Digital Twin is a solution that can help visualize each factor related to the energy management systems

that the urbanized centers would like to employ. It can help see the effects of energy at both the economic and environmental scale.

3.2.3 Livability Issues

Digital Twin can play a large role in aiding urban planners with routes for public transportation. Not many cities prioritize public transportation as a part of their urban sustainability frameworks, and Digital Twin is there to help fill in the gaps.

Public safety is a matter that is very important in urbanized centers, as a city is only sustainable if the people living in it can thrive. Digital Twin serves as a solution, being able to predict events like traffic accidents for law enforcement to aid the public as quickly as possible.

3.2.4 Cultural Issues

It was mentioned in section one that most urban sustainability frameworks place little importance on aspects like culture, but there is a solution to this. Digital Twin can help with cultural appropriation and cultural heritage. One solution, proposed by Marijana Ćosović and Mirjana Maksimović in their research paper titled “Application of the digital twin concept in cultural heritage,” we can see that the Digital Twin is a viable solution in solving these issues as well. They argue that Digital Twin can be used to preserve historical monuments.

3.2.5 Overall

To summarize, Digital Twin technology effectively addresses the three issues detailed in section one: focus, data collection, and environmental challenges. By offering urban planners a centralized platform that integrates all necessary factors for identifying problems and making informed decisions, Digital Twin provides a superior approach for planning urban sustainability.

4. Prior Use Cases of AI for Urban Sustainability

The Use of Digital Twin has been massively popularized in the past few years. Thousands of companies were reported to have adopted some form of a Digital Twin last year. According to market.us, “[the] Global Digital Twin Market size is expected to be worth around USD 522.9 Billion by 2033, from USD 11.8 Billion in 2023, growing at a CAGR of 46.1% during the forecast period from 2024 to 2033” (Market.us). This recent explosion of Digital Twin is not limited to enterprise use only, as several countries and cities are also implementing Digital Twin for many systems. Additionally, Digital Twin has expanded to the realm of healthcare. A report made in 2022 by Saleh Alrashed, Nasro Min-Allah, Ijaz Ali, and Rashid Mehmood explains how Digital Twin was used to help slow the spread of the Coronavirus (COVID-19) disease 2019. To slow the spread of a disease of such a magnitude is very difficult, as many factors are associated with a disease of such complexity. Using Digital Twin, authorities were able to plan correctly, vaccination centers were improved, and more.

4.1 Use of Digital Twin for Urban Sustainability

Singapore's implementation of Digital Twin technology is impressive and stands out as one of the most noteworthy examples of its use. Data for the 3D map is fed in through aircraft and vehicles to capture terrain and street data. The model, which operates at a high level of detail, is used to aid in decision-making for urban planners, government agencies, and more. Although recently created, it has already been used to partly solve issues with natural disasters and flooding in Singapore. Singapore has also created another Digital Twin called the Open Digital Platform, which is used in the Punggol District. It collects data from cooling, security, waste, and facility systems to create the AI model. The ODP allows estate managers to manage efficiently.

Austria, taking inspiration from Singapore, has started an implementation of a city Digital Twin in Vienna. The city has created several projects for its key systems, each using a unique and specially tailored Digital Twin technology. One such example is a Digital Twin used to “increase grid capacity and accelerate energy transition” (Carlson), created by a company named Siemens. Siemens has implemented the Digital Twin in a part of Vienna, Aspern Seestadt. The Digital Twin is being used to model the entire electricity network, which highlights important information needed to implement renewable energy and increase capacity.

Another European city using a Digital Twin is Helsinki, which in partnership with another city, Tallinn, has created a digital twin called Green Twins. By creating a 3D model of green landscape, as well as the urban spaces within these cities, they can test both landscape changes and urban planning. Specifically, they look at changing urban vegetation by predicting “growth patterns and seasonal changes in the local climatic conditions” (FinEst Centre for Smart Cities). On the urban planning side, a great example of using Digital Twin is in old town areas, which can use pedestrian traffic areas to optimize restaurant opening times.

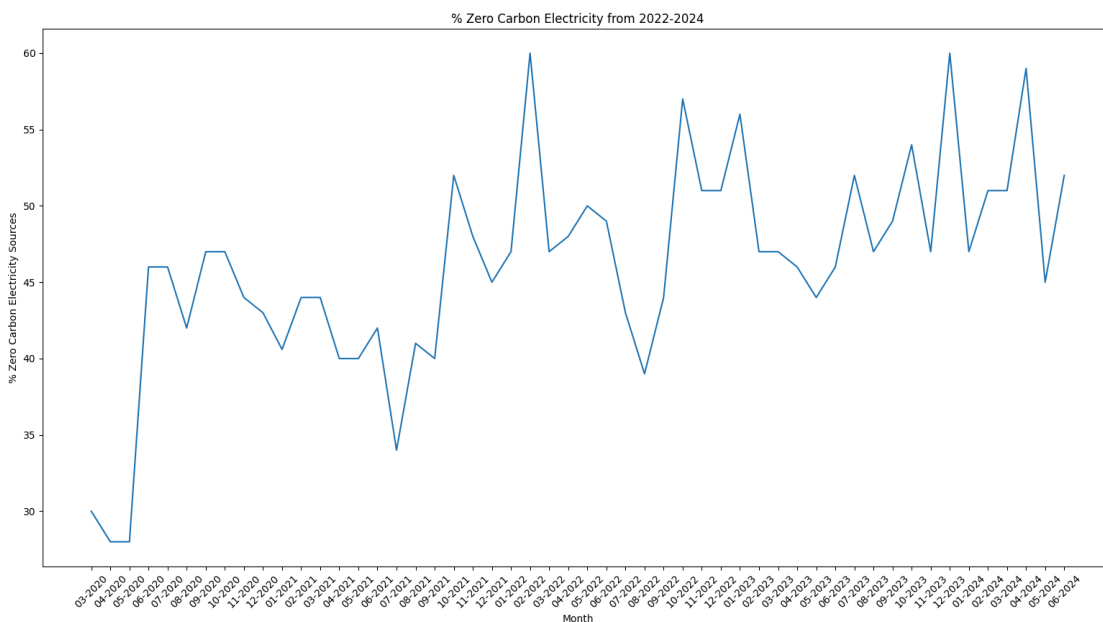
San Diego is also looking to implement Digital Twin technologies, more significantly in their water management systems. The Pure Water San Diego Program used Digital Twin technologies on several major water treatment facilities to create the plan schematics and structure. It was used in the design phase of the project to model how the system would work. The plan aims to provide 40% of the city’s water by 2035. The project will be implemented in phases, with phase one focusing on recycling clean water into a highly purified version.

The final country that will be looked at in this analysis of Digital Twins is the UK. The UK has implemented a “Virtual Energy System,” designed by National Grid ESO. The main goal of this system is to decarbonize the energy system, which is a leading source of greenhouse gases

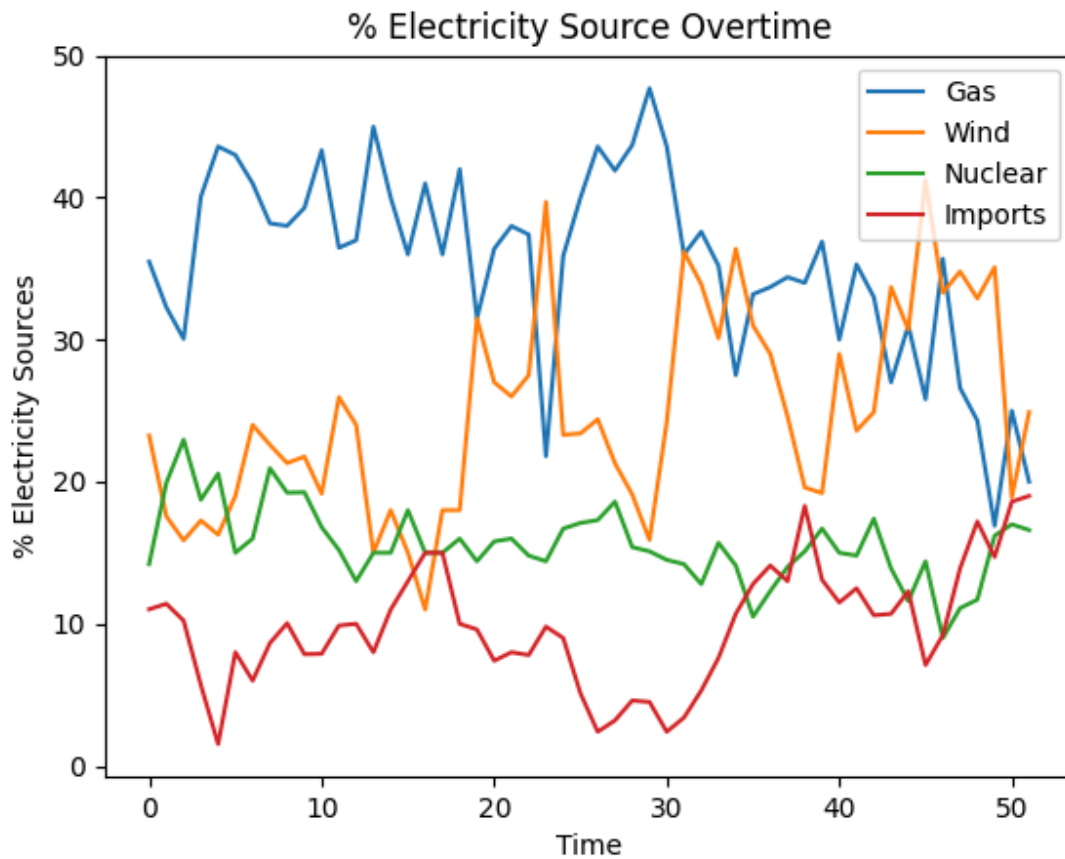
in the UK. The system works by being populated by smaller digital twins, which provide real-time data to the whole system. The collection of the data from each smaller digital twin will allow for smarter decisions to be made. The idea of an interconnected system of smaller digital twins making up a larger one is novel, and sure to be implemented in several other digital twins worldwide.

4.2 Data Collection

To highlight a Digital Twin's impact on a country, data was taken from the previous example of the UK's digital twin to analyze the benefits. The dataset we used for our findings was the monthly electricity statistics of Great Britain, provided by National Grid ESO. The data ranges from March 2020 to June 2024. The statistics that we captured were the percent of zero-carbon electricity sources used in Great Britain per month, as well as the percentages for each electricity source such as gas, wind, nuclear, biomass, coal, solar, imports, and hydroelectric. Here is a graph modeling the trend of the percentage of zero-carbon electricity sources throughout the time in which the data was collected.

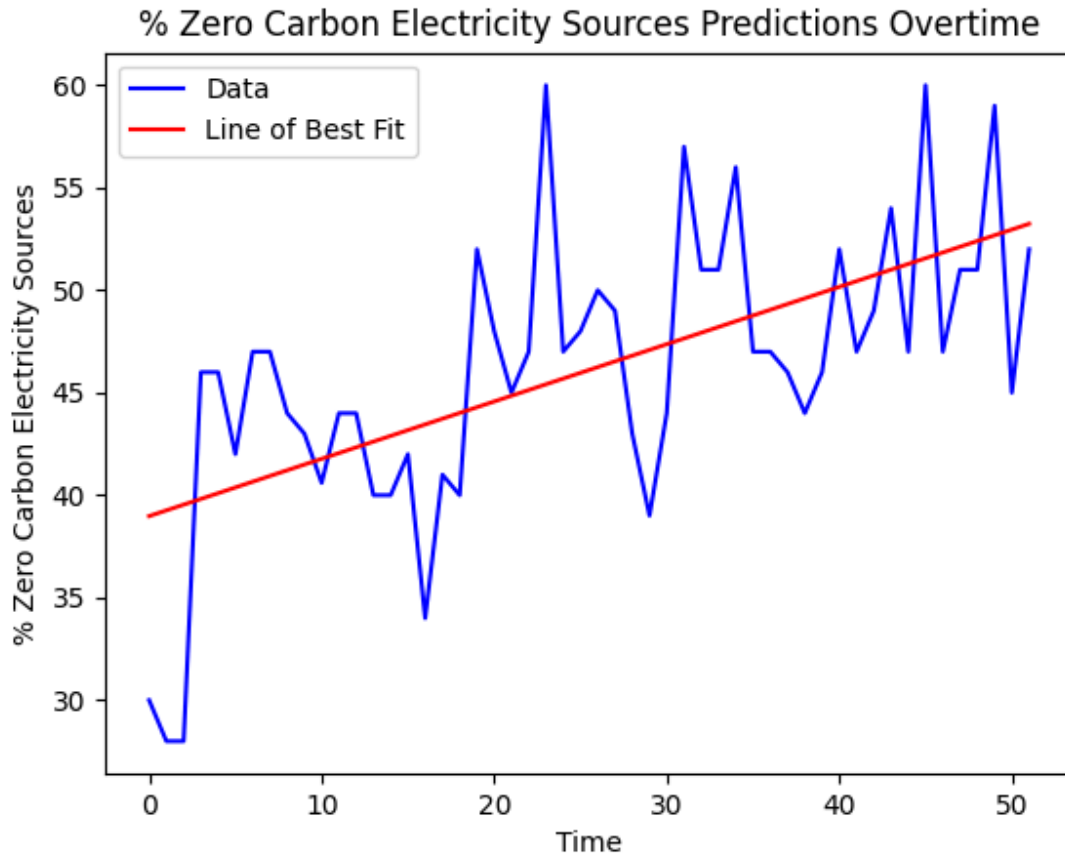


We can see that the general trend points towards an increase in the use of zero-carbon electricity sources after around June 2021, which is approximately around the time that the Digital Twin model was implemented. By modeling four of the main electricity sources for the UK in this period, we can see that for the bulk of the time, gas was the leading electricity source. However, after changes were made thanks to the help provided by the Digital Twin model, the wind has become a prevalent electricity source for the UK, at times being the leading source of electricity during particular months.



It can be seen from the graphs that the percentages are modeled over time, which we define as the time in months where zero is the start of the dataset and each additional time unit is

one month. This was done to facilitate the implementation of a simple Linear Regression model using one feature to predict the general trend of these percentages.



The model shows a general upward trend in the percentage of zero-carbon electricity sources over time and predicts that it will reach a value of around 55.20% by the end of the year. The same was done for the percentage of gas as an electricity source, and wind as an electricity source and we see a downward trend for gas and an upward trend for the wind. It was predicted by the model that the percentage of gas would reach a value of around 27.15%, and the wind would approach a value of around 33.27%. These percentages show an overall improvement in the quest for decarbonization since the model was implemented.

6. Negatives of Using AI

Regardless of all the data collected and presented throughout this paper, there are still drawbacks and flaws with the Digital Twin technology which must be mentioned. No urban sustainability system will be perfect, and Digital Twin is no exception. There are many concerns about using the new technology. Some of these categories include data privacy, cyber security, data quality, community distrust, and bias.

6.1 Data Privacy

The success of a Digital Twin relies on how good the data is. If misleading, incorrect, or insufficient data is being provided in the model, then the predictions will also be faulty. However, concerns may be raised as to how data is being collected, or what data is being collected. For most, privacy is a big concern and if Digital Twin models utilize sensors to capture data that the population otherwise would not want to be made use of, there can be issues.

6.2 Community Distrust

This flaw ties into the previous flaw of Data Privacy. Not only can it be hard to trust the data collection methods of the agencies and corporations behind these Digital Twin models, but it can also be hard to trust the accuracy of the virtualized entities. Huge decisions are being made with the Digital Twins, so it can be concerning for many that a “computer” is making these decisions for them.

6.3 Data Quality

It was mentioned previously that the Digital Twin model is only as good as the data, leading to the next major flaw with Digital Twin. The data quality must be high for a highly accurate and predictive model. Otherwise, it is hard to depend on AI to present us with predictions that can be trusted.

6.4 Data Bias

The final flaw related to the data collection of Digital Twin is the possible bias the data may have. Again, the data collected determines the success of the model, and if the data collected is processed in a biased manner, the results may be unfair.

6.5 Cyber Security

Finally, cybersecurity is a massive flaw within the Digital Twin model. Having such an important data center requires top-notch security, as the data getting into the wrong hands is one of the worst things that can happen.

7. Conclusion

Through the extensive amounts of research done, and the data collected and analyzed, we have concluded that Digital Twin is a viable solution for the future of urban planning. Digital Twin perfectly fills in the gaps with the current models of urban sustainability and can improve current methods of solving many of the issues in urban spaces worldwide. The use of Digital Twin in a corporate environment and an urban environment, such as in cities and countries, further backs the claim that Digital Twin is the future of urban sustainability. The benefits can be seen through the visualization of statistics benefitted by the implementation of a Digital Twin in an urban space, showing a clear upward trend towards solving a goal or problem. Although there are drawbacks that come with using Digital Twin, it must be noted that no urban sustainability model will be perfect. Yet, the benefits outweigh the negatives of using this technology. Digital Twin is a promising new technology that will be able to impact cities positively, allowing them to scale to the explosion of the global population growth yet to come. Digital twins, when combined with AI and other advanced technologies, enable real-time monitoring, simulation, and optimization, significantly enhancing decision-making and efficiency in urban sustainability.

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