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Master in

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City Information Modeling (CIM) as a Vital Digital Twin for Improving Sustainability

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STATEMENT OF INTEGRITY

I hereby declare having conducted this academic work with integrity. I confirm that I have not used plagiarism or any form of undue use of information or falsification of results along the process leading to its elaboration.

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SOMMARIO

Oltre 3,9 miliardi di persone vivono attualmente in aree urbane e suburbane, rappresentando il 54% della popolazione a livello globale. Tale tendenza di urbanizzazione continuerà a crescere nei prossimi anni portando la popolazione delle aree urbane a 6 miliardi entro il 2045. Le aree urbane rappresentano l'80% delle emissioni di gas serra, il 75% della produzione di rifiuti e il 70% del consumo energetico a livello globale.

L'edilizia sostenibile e una pianificazione urbana integrata diventano ancora più necessarie dalla crescita dell'urbanizzazione e la crescente domanda per una migliore efficienza nei consumi energetici e nella gestione delle risorse naturali. Il grande avanzamento delle tecnologie dell'informazione nei modelli di città 3D, Digital Twins, Urban Analytics, Geographic Information Systems (GIS) ha avviato la recente transizione digitale.

La modellazione delle informazioni della città (CIM) significa implica la gestione di enormi quantità di dati, che successivamente vengono riuniti utilizzando il cloud computing. La CIM si occupa della gestione integrata delle operazioni di trasformazione urbana e sintetizza le riferimenti paradigmatici attuali tali come sostenibilità, smartness e resilienza. In questa tesi si presentano i concetti esistenti sulla modellazione delle informazioni della città sulla base di una revisione critica della letteratura.

L'uso della tecnologia è indispensabile per migliorare l'efficienza e l'efficacia della gestione delle città, migliorando così la qualità della vita della popolazione. Alla luce di quanto sopra, gli urbanisti e i governatori dovranno affrontare sfide sostanziali per quanto riguarda le attuali e future esigenze in materia di pianificazione urbana, gestione e monitoraggio delle città.

Parole chiave: (BIM, CIM, Digital Twin, GIS, Sostenibilità)

ABSTRACT

More than 3.9 billion people now live in urban and suburban areas, accounting for 54% of the global population. This urbanization will continue to grow in the coming years, bringing the population of urban areas to 6 billion by 2045. Urban areas account for 80% of greenhouse gas emissions, 75% waste generation, and 70% global energy consumption.

The growth of urbanization and the rising demand for better efficiency in energy consumption and management of natural resources makes it necessary to deal with building construction and city planning in new and sustainable ways. Information technology progress in 3D city models, Digital Twins, Urban Analytics, Geographic Information Systems (GIS) have promoted the recent digital transition.

City Information Modelling entails dealing with enormous amounts of big data, commonly brought together, utilizing cloud computing. CIM provides the integrated management of urban transformation operations and synthesises current paradigmatic references such as sustainability, smartness, and resilience. This thesis presents existing concepts on the Modelling of City Information based on a critical literature review.

The use of technology is indispensable to improve the efficiency and effectiveness of city management, thus enhancing the population's quality of life. Given the above, the urban planners and governors will have to face substantial challenges as to actual and future demands in urban planning, management, and city monitoring.

Keywords: (BIM, CIM, Digital Twin, GIS, Sustainability)

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1. INTRODUCTION

This thesis is based on research, literature review and evaluation work of City Information Modelling, its challenges, sustainable development, and benefits from standardized indicators worldwide. City Information Modelling is a concept firmly embedded into how cities and their infrastructure are managed and used nowadays. The first topic elaborates a broad view of how city infrastructure works, what comprises it and how the smart city concept has evolved. These relate to the prerequisites of the implementation of how new services and intelligent infrastructure can be automated through data generation of physical buildings, infrastructure, how services and economy generation through different business models, can impact today's living metropolis. Smart cities management infrastructure clearly shows the potential of today's urbanization, its impact on the environment, and people's practical lifestyles.

Smart cities and urban infrastructure have a very keen relation to geographical location, services, buildings, and all information generated are in an unchained correlation to geographical data processing. In this regard, the topic aims to give an understanding of how geo-location data works, is processed and what analysis can be performed through tools such as ArcGIS or other spatial analysis of processing data.

IoT is becoming more and more the crucial part of today's development that links the entire physical urban built environment and infrastructure to automated processes and data gathering. This explains IoT infrastructure and how software systems are built according to infrastructure, environment, business, and policymakers needs and requirements. IoT is becoming an unseparated part of services, and a new range of service businesses are raising, processing these economic behaviours through data analysis. IoT system architecture views the built software architectures in customising it to specific devices or a different range of sensors. The big data gathered are run and processed through these architecture customizations of software.

Further exploration of CIM regarding sustainability guidelines and standards to emission reductions and energy efficiency in the built environment provides a new approach to using the data gathered to model and monitor environmental issues that concern the urban living environment. BIM is a fundamental part of this issue; buildings and construction have the most significant role in going through a CO_2 reduction process considering energy efficiency, sustainable raw materials use and automated processes.

Advancement of building information modelling at a larger scale like CIM, Digital Twins as a progressive concept, puts City Information Modeling into a mirrored digital virtual motion that enables simulation to improve effectiveness, sustainability, processes, etc for better economic and political decisions. Digital Twin as a data gathering hub mirroring the built environment is becoming a very effective tool for shortening time in the decision-making and reducing cost estimation without working in the real environment. The Warrington Borough project case, through ICL (Intelligent Community Lifecycle) digital twin tool explains how CIM is used for analysing various scenarios of community energy reduction measurements, network energy distribution and storage.

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2. SMART CITIES URBAN INFRASTRUCTURE

City as Socio-Technical System

Cities are places where people work and live together. This is considered from different perspectives; some people see it as an economic system, a generation of wealth, jobs, and economic conditions of working and interactions. Another approach looks at it as a social system related to the way of life, cultural life, social life, activities, and social interactions. Other see cities as a political system, how people interact, who decides about what, who owns the power and how decisions are taken. At the same time, some other people see cities as technological systems where infrastructure is the foundation of the technological system. All these ways of perceiving the city are correlated with each other and consider it as a socio-technical system.

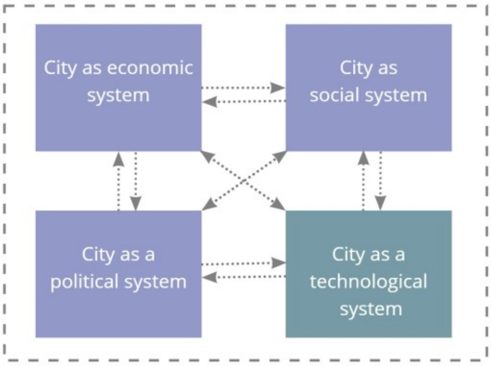

Figure 1– City as a socio-technical system

All these perspectives of seeing the city as a different system affect each other, e.g., technology the way it works, effects economy, economy effects in its way in reverse the investments in technology and this goes the same as to social and political aspects. This is the general systemic view of a city.

Urban infrastructures promote the cohabitation of living and working environments. It has an effect on how people work, live, and make decisions. You may observe how infrastructure is constructed with the influence on social life in mind, such as the ease with which the city centre is accessible, the influence on traffic, whether it is flowing or not, on the effectiveness of the water supply, and on the quality of social, economic, and political life as a result of all of this. Infrastructure is essential in determining the growth, maintenance, building, and investment in various areas of the city. It deals with the process on how industrial zones and business parks are chosen for development and how all of these concerns contribute to the city's complexity as a socio-technical system that determines its infrastructure and social life.

Transportation, buildings, housing, electricity, water, wastewater, and trash are all constituent infrastructure elements. All of these are critical components of a city's social, political, and economic life. These major concerns influence how transportation is built, whether water is clean or not, whether energy is renewable, and whether the socio-technical system may be viewed as part of a broader metropolitan system. Of great importance here is the impact that all of these system parts have on city administration and government and the ability to receive input from them.

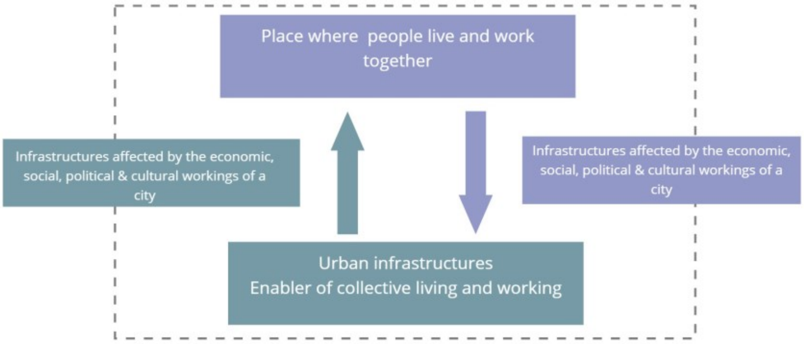

Figure 2 – Urban infrastructure collective living & working

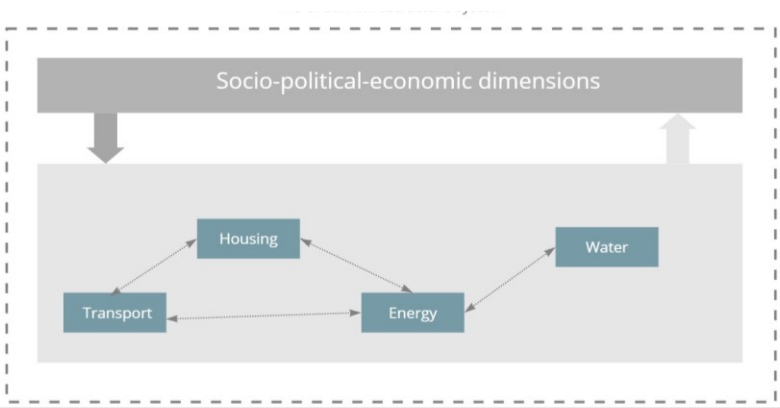

Figure 3 – Urban infrastructure system

1.1. Management and Governance Implications

There are many implications on the systemic view of cities which of primary importance is management and governance of the cities. The concept of loop feedback can be considered. All the elements mentioned in the system interact with one another, and they create feedback. The technical part interacts with the social part, and these dimensions are also in interaction with the economic dimension, which all create feedback loops. This kind of interaction makes cities very complex, and outcomes are never attributed to only one cause but to a correlation of all elements.

Additionally, this situation places these elements in a path-dependent interaction, e.g., decisions made in the past reveal their consequences in the future. The city and its infrastructure are socio-technical systems that interact, generating feedback loops on both sides. The housing process impacts transportation. Transportation affects energy, and all of these feedback loops affect what happens inside a city. These feedback loops develop similarly in the social realm. Numerous actors interact, and economic activity affects social life. Thus, how these layers of technical and social dimensions are layered affects how people work, whether they get to work or not, whether they have access to water and other essential services. All of this directly affects how the city performs, how resilient, efficient, and sustainable it is. All these feedback loops make the governance of the cities very complex and unpredictable, and that is a crucial issue to be considered.

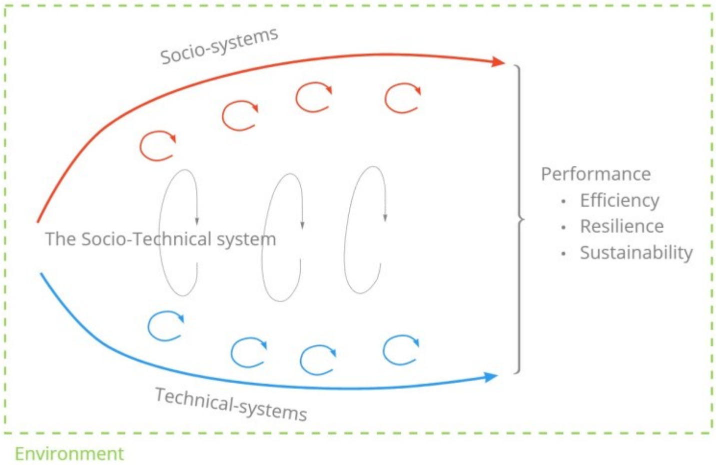

Figure 4 – Systemic view of cities

1.1.1. Implications of Digitalization

- Data Generation and Storage
- Networks and Communication
- Internet of Things (IoT)
- Data Analytics

1.1.2. Data Generation and Storage

Data are generated from many sources such as cameras, sensors, RFIDs, GPS, including all the information called self-generated, e.g., through smartphones that are constantly transmitting and generating data.

These data are generated and used more and more by smaller devices at a lower cost. The storage capacity where this data is gathered is growing every day, making an unexpectedly amount of data gathering. This exponential data gathering storage makes the first element of digitalization.

1.1.3. Networks and Communication

The second element of digitalization is composed of three elements, generally named communication and network, which have three different dimensions that relate together. The primary layer of telecommunications infrastructure is the cables, the fibres, wireless infrastructure, and the capacity bands, which grow into 1G, 2G, 3G, 4G, WiMax, WiFi, Satellites. All these comprise the telecommunication infrastructure of the transmitted data. The second layer is the networks in which different devices are used and connected, which is usually done by protocols, connecting the different data storages and storing devices together. The third layer is the identification and exchange of this data, which is usually called the worldwide web that records the devices' locators, e.g., computers, phones, etc.

1.1.4. Internet of Things (IoT)

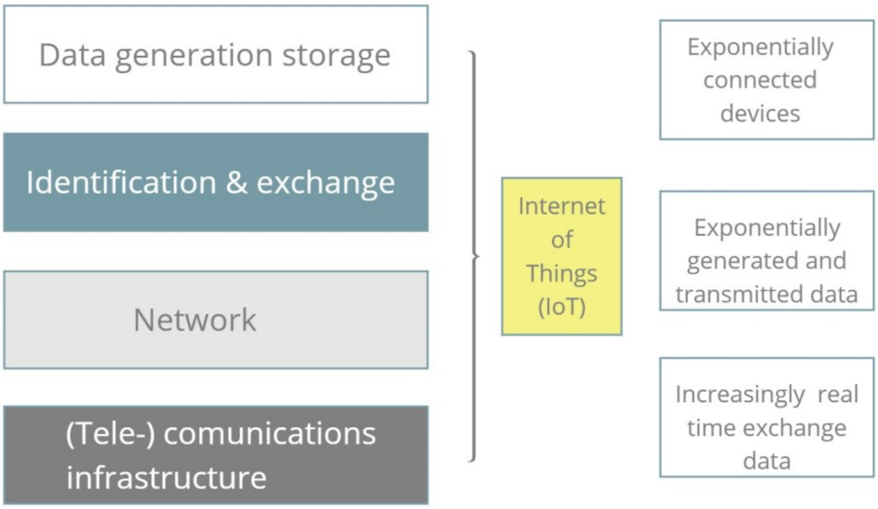

Figure 5 – IoT layer structure

Four components constitute the IoT: the devices that connect the data and the identification and exchange of data of different devices connected through the internet. The speed and the data transmitted through network infrastructure and the devices types and capacities, now and on, are often replaced with the ones with small size and lower prices. All these have growing capacity, and more and more data needs to be stored, generated, and transmitted at an increasing speed, and some devices do not need any more power, e.g., RFDI's. All these components make the IoT the part where devices linked together through the world wide web will grow exponentially in five years. A survey has shown that the number of devices connected through each other will double by this amount of time. Then the data generated and transmitted will be exponentially increased, and the bandwidth of these data devices will take and use up to 50% of all of it. Nowadays, it is possible to supervise your house and work remotely through smartphones in real-time, and that is possible through what we call IoT.

1.1.5. Analytics

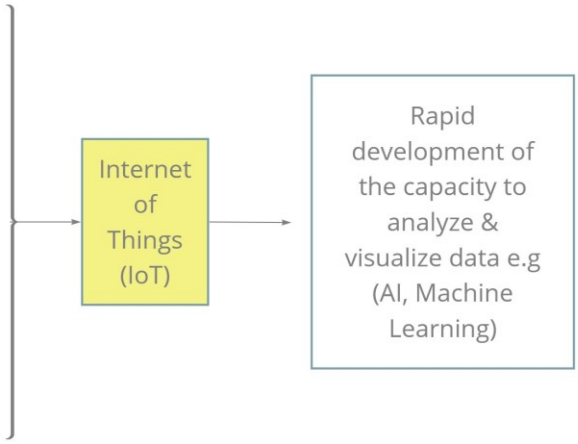

Figure 6 – Visualized IoT data output

In addition, analytics is an important factor to consider. This data must be expeditely analysed, processed, and sometimes visualized because analytics cannot always show what needs to be analysed, the outcomes, and how they are received. This amount of data, referred to as Big Data, is processed by using artificial intelligence and deep learning tools such as machine learning. In conjunction with one another, all these elements, such as storage, transmission, networks, analytics, comprise the overall concept of digitalization.

1.2. Implications of Digitalization on Industries and Infrastructure

1.2.1. Industries

Generally, all industries have a chain production line, a physical value chain line, e.g. a car production is assembled on different stages and sold as a finished product. The customer is finally interested only at the finished product of the value chain, usually the retailer. Digitalisation makes it possible to mirror the physical value chain in a data layer. All the information in the physical value chain is embedded and duplicated in the digital layer. While the physical value chain still exists, another mirrored information in a digital layer makes it possible for the customer to connect directly. The customer can order directly from the internet and can assemble his vehicle. He can choose the materials, the type of the parts through a digital interface. For example, one can order a PC and assemble its parts on his ow own. There is another benefit from this digital layer of information; this can be used to produce new services, products or business models with the same customers or new ones.

Amazon's business model can be considered as an example: a product that is yet under production can be ordered digitally, and it arrives at you physically. The second layer is where, as a customer, one can get advice on what other people similarly purchased and what other available products are there and how it is possible to profit from the data stored on that digital layer. These are new services and business models. Many industries can benefit and be affected by this potential of mirroring digital information. For example, in education and health care, a large amount of information is generated. All of this information on a digital layer can be repackaged and sold to new industries. Digitalization can disrupt any activity with a value chain, but some are more vulnerable than others.

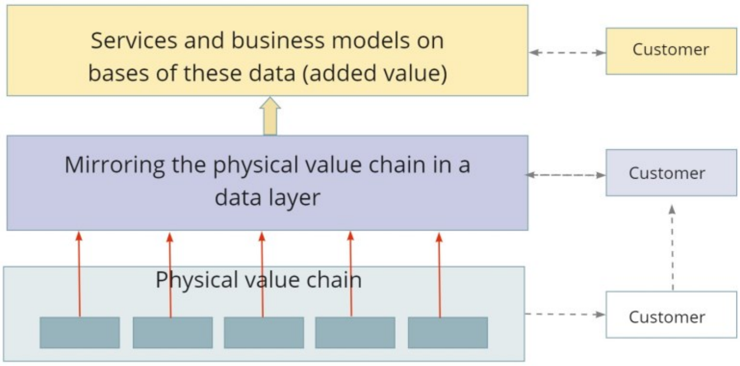

Figure 7 – Implications on Industries & Infrastructures

1.2.1. Infrastructure

The infrastructure and services are also linked by the digital layer, which connects customers and infrastructure-provided services. Customers are not directly connected to the infrastructure's services; instead, they are introduced to data via a digital layer in between, similar to the industry case topic. This in-between digital layer improves the efficiency of infrastructure management, resulting in an optimised physical value chain. This digital layer can obtain smarter energy management, smarter transportation management, smarter waste management, and other smart city features.

Another element to consider is the new kinds of services provided from the digital layer; these new services are also considered smart new services. These new services can create new business models that can be determined. The city can advise, or companies can offer, for example, services about saving energy, offering new services combined with infrastructure. The first approach manages and combines elements of optimisation, incremental innovation, and the already existing infrastructure that can be improved through the digital layer. The second is related to the qualitative changes offered by these new types of business thanks to the digital layer such as energy service, transport, waste services, green services etc.

1.3. Smart City Perspectives

Smart cities are used in different ways, with smart cities, some mean mainly the economic dimension of “smart cities”. They refer to the digital layer economy; this is the primary concern about how the city generates jobs, revitalizes, and stimulates its economy. In this era of new information and communication technologies, this is perceived through innovation parks, partnerships between universities and industry, and smart city is a digital economy that can be simulated. Another dimension of looking at smart cities is the social dimension of digitalization, here is the potential to stimulate community life by way of online communities, social interactions, and cultural life in a city.

The third point of view is that the digital economy and the sharing economy are inseparably linked. When they are combined, they see the smart city as having a political dimension. This refers to the potential of digitalization to simulate citizen participation, civil society involvement, or other stakeholder involvement through concepts such as, e-governance and e-participation.

The fourth and most important point of view is that smart cities are primarily focused on the technological dimension, on infrastructures. That is the most widely accepted definition of a smart city.

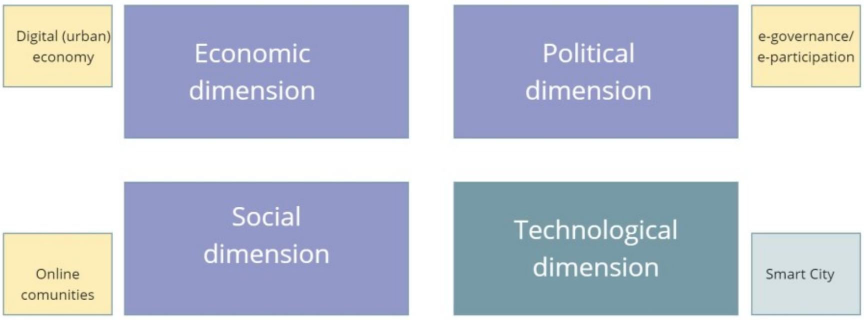

Figure 8 – Smart City dimensions

Smart cities from infrastructure and technological dimensions include, e.g., elements like transport, smart cards, online information mobility as a service, on energy level there are smart metering, smart lightening, digital water metering, smart housing, intelligent buildings, energy savings and so on.

Another dimension is also into the environment direction, which goes through smart waste, smart green infrastructure, and many others in the sustainability dimension. All these considered in the wide picture are the implications that digitalization has on the urban systems.

The main implications that digitalization has on urban systems are four. The first implication is on the management and infrastructure itself, e.g., the combination of the existing infrastructure and the new possibilities digitalization offers. There are implications established in new services and opportunities deriving from services that lead to other managing and governing implications. Another implication is about managing the data layer and altogether that compound the urban sociotechnical system. This urban system implication goes on a higher level in governing this system and specifically the institutions.

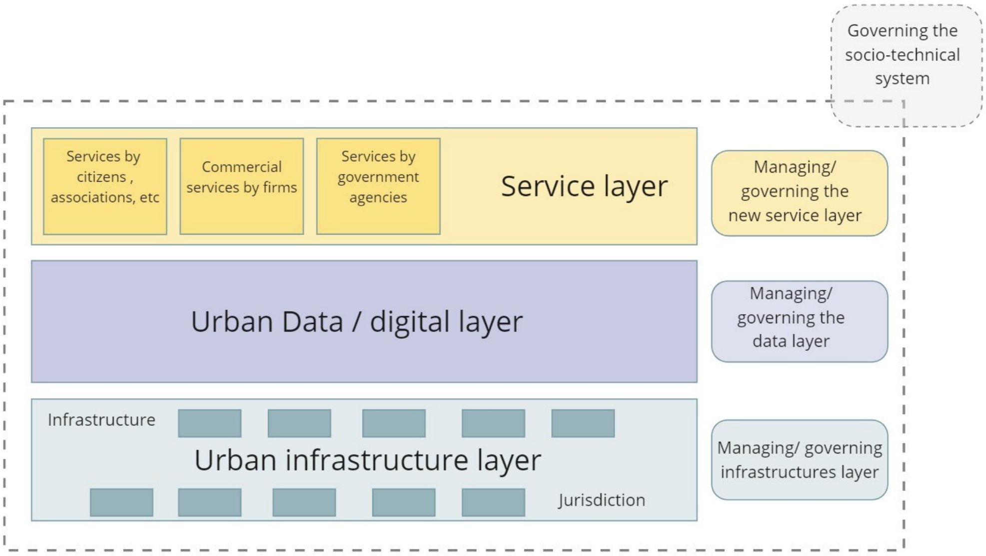

Figure 9 – Implications on management of the city

The concept of smart city nowadays is not anymore, an academic concept; there are many elements to be considered, mostly it is a concept pushed by vendors and specific cities. The academic contribution to it is the distinction between the infrastructure, the digital data layer, and the services based on the data layer. Unlike the academic perspective of smart city, this concept is also put forward by other private companies that promote smart city.

The first perspective is that of hardware vendors that produce different kinds of devices such as generating devices, like smart meters, sensors, cameras, etc., which contribute to creating the digital layer. The second perspective is the one of the infrastructure companies. Unlike the device production companies, these are focused and active in the urban arena. They might be water companies, electricity companies, transport companies, even telecom and postal services. They are also advancing the concept of smart city because they work on their infrastructure via the digital layer and services.

There are also other vendors, companies such as IBMs, Ciscos of the world that offer services that integrate and analyse this data. So, their work is managing on metropolitan areas city's perspective through integrating services, citizens, and businesses. These perspectives influence two factors: the first is that vendors are attempting to monetize the services that they are providing, and they are analysing citizens as customers of the services that they are proposing, and the second is that digitalization offers many opportunities, and this needs to be observed more closely on demand for vendors to adopt these technologies.

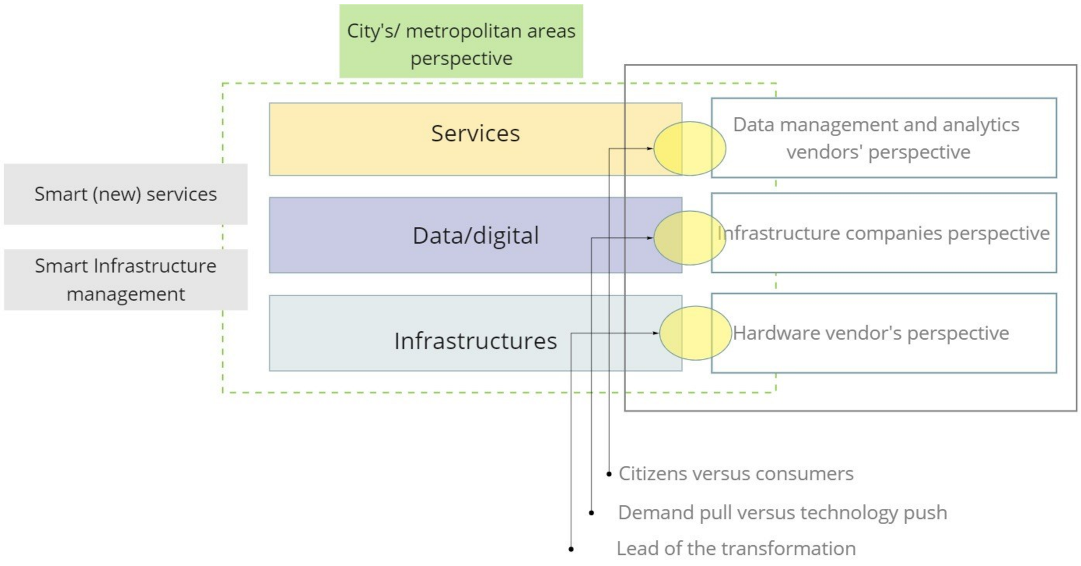

Figure 10 – Vendors perspective

1.4. Smart Urban Energy Systems

Smart urban energy systems derive from three main drivers that are at the same level. Urban infrastructure technologies have been changing, and with decentralized production, renewable technologies, transport technologies, and energy technologies have been affecting urban energy.

The first driver is that technologies related to the energy sector are continuously changing and affecting urban energy. There are being produced and taking more place electric vehicles, buses, bicycles electric charging stations associated with them. There are housing technologies that are constantly changing and improving; houses are becoming more self-sufficient and producing their energy themselves. More changes have taken place in the heating district, in heating pump storage etc. The second driver is climate change resource efficiency. Cities are becoming big polluters, and the aim to reduce Co2 emissions and become more energy self-sufficient is one of the most crucial objectives of urban energy systems. Digitalization is the third driver and the necessity in which the urban energy systems can become smart.

Traditionally energy is produced by power plants in a centralized way. Transmittance systems distribute the electricity into the city and to the whole households, companies, areas, airports, shopping malls etc. This is the traditional linear way of distributing central production to the decentralised distribution process.

The first new concept that is evolving and taking more and more place is the new way of distribution. However, the traditional centralized distribution is still working but has it become less critical over time. Factories, households, devices, etc., are ever producing their energy, and some feed the electricity system at certain times. The second concept is energy generation at irregular intervals or occasions based on energy production thanks to renewables such as solar and wind. The solar electricity production can be in decentralised or centralised massive solar plants and then fed back to the grid of transmittance. The other major issue is the one that is related to energy price regulation and optimization. Instead of having fixed prices, consumption signals and measures indicate the consumption trend and areas, so the energy can be stored in decentralized or centralized backup batteries or dams to be fed back into the grid system when prices are high. All these processes are automatized, and these are the core features of smart urban energy systems. The automated devices can react to the price indicators to turn off when the prices are high and turned on at times the prices are low.

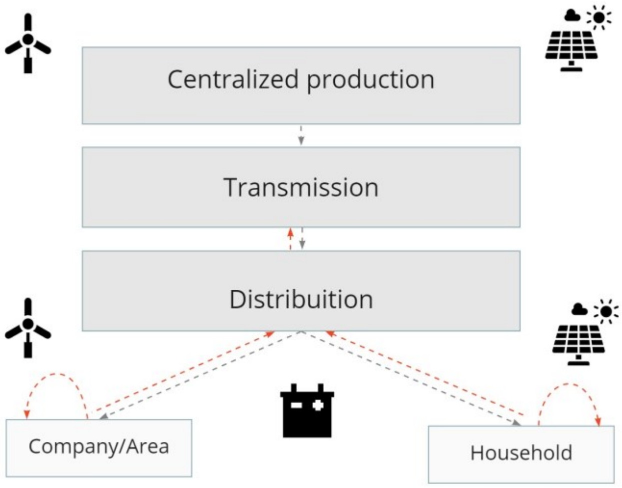

Figure 11 – Electricity distribution system

The main layers of which the digital transition consists of are; The first is the urban electricity system. An integrated electric system means the possibility where firms, areas, households, etc., are self-generating and feeding the system grid. However, the primary sources of electricity are fed from the outside. A larger environment is affected directly by urban energy and electricity. In this socio-technical system, factories, e.g., are electricity producers and stores and can be active in energy matters or trade. The second layer is one of the services.

The third layer, the data layer, concerns the consumers of energy and electricity not only as consumers but as prosumers at the same time. A significant number of devices, systems, and services are related closely to electricity demand, e.g., more and more electric cars, buses, bicycles, and households are in constant demand for energy. Buildings also are in great demand and related to electricity systems by consuming and feeding back. Gas production, water supplies and other water systems as wastewater are related to electricity. Electricity can also be produced from waste, and all these examples of energy use and production form the urban electricity system. Furthermore, the services at this stage became more complex, they are not just buying energy, but they are storing, managing, and selling simultaneously; this layer makes energy systems possible.

Smart electricity systems as an integrated utility are seen as a linkage to other urban infrastructure systems. There is much interference with a range of other dimensions; one can be the electric grid itself, such as the increase of photovoltaic panels, local PV systems, or other infrastructures like heating pumps as new infrastructure heating sources. Such interference with each other and these technical linkages also correlate to socio-technical systems and political-institutional aspects. The

Paris CO2 agreement is a central goal directive towards the reduction of pollution emissions. The economic and social dimension is also considered in connection to the liberalization of electricity markets. It provides good living quality through infrastructure and service to the customers and citizens. Many other opportunities can be achieved through the linkage of smart urban electricity systems as decentralization, digitization that can improve sustainability, increase efficiency, and raise the quality of life. These systems generate data that would attract new business development and create new established digital marketplaces. This value chain foresees also challenges as to the financial, regulatory, competencies and bringing collaboration through stakeholders.

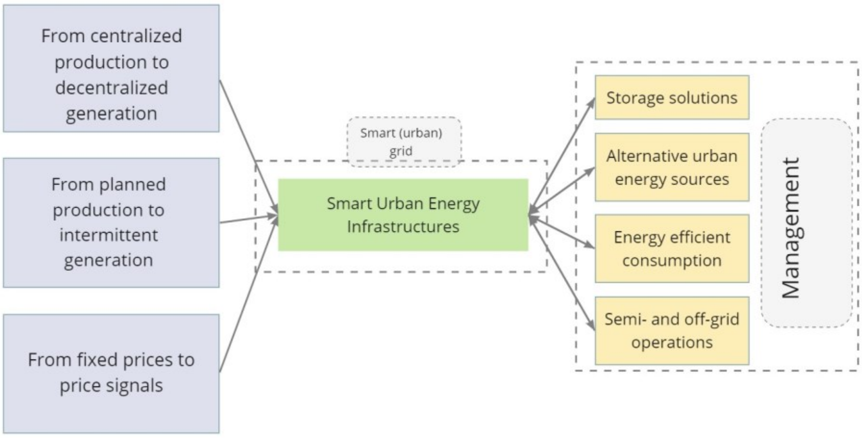

Figure 12 – Smart urban energy infrastructure

1.4.1. Actors Involved

There are several actors involved that interact with one another, and that must be coordinated. There are prosumers, the ones that consume and produce electricity at the same time. Those could be industry and households. Then there are the decentralized producers of electricity, which can be like prosumers, but they can also produce their energy, e.g., waste facility that produces electricity. Other actors are the storage operators, which can be transport or storage operators on their own. The other actors are the distributors. Usually, there is one urban energy distributor, but with of-grid and semi grids, i.e., more than one, they need to be coordinated and interacted. Both the transmission system and different operators are the actors that feed the electricity into the city, and at times, they can also take the electricity back to be stored. Thus, the centralized electricity producers need to be coordinated. There are the traders that fluidify the production and consumption of electricity by linking all the actors. All these actors can emerge and play their role and interact in the smart urban energy system through the coordinated management of the digitalization process.

1.4.2. Smart Grids for Cities

There is an assumption that a big part of the electricity is generated during the distribution process. Essentially that is true in the case of renewables, such as PV's of rooftops, centralized power plants, wind turbines etc. The integration of these resources brings two challenges; the first is that these resources are not centralized. They are spread over all territory, making it difficult to control them from the aggregated perspective, so there is a need for smart grids. A range of tools that provide sensing is needed for developing smart grids and situation estimation with automation and operators that make it possible to measure the exact status of assets and quasi-real-time valuation results.

The second one is a technological requirement, the ability to observe and sense the system status. In systems of a neighbourhood, a city, a country, or even an entire continent, it is like the automatic cars developed with autopilots. One has to build the situation surrounding the car. So, the second requirement is to be able and capable of controlling the systems, which means the usage of storage. Large sets of battery storage are needed in the future smart grids to control and provide services to the power system from the local level.

As power systems in smart grids can have the sizes of neighbourhoods up to a country or continent, the collected sensing quantities face the problem of information gathering. There is a need to adopt mechanisms to achieve synchronization either through GPS or satellite synchronization systems or different protocols brought through the internet for the time delay. Once the synchronization is settled, it collects and measures the situation awareness, which is shared with the automatization of local intelligence devices. This takes control over the small asset devices like the controllable load of a small tv battery, analytical vehicle charger, and so on, making devices negotiate with each other. This transition is more on the software part; the physical systems are needed like batteries to store energy efficiently and release it controllably. The lifecycle of devices is also a reason to consider. These assets can do more than 15,000 cycles, several decades, which means they can have similar performance to power industry assets that last relatively 20-25 years.

These smart grids power systems are also dependable on the institutional regulation and managerial perspective, which is often a challenge in these socio-technical systems. Typically, these power devices as energy storage are used by power utilities that are not supposed to own energy storage because they can do energy arbitration in the energy markets. In this view, they can influence the demand, and they can purchase and store energy. When the energy price market is low, they know it in advance and resell it when the prices are higher. So, in this case, regulatory bodies are meant to develop tools to regulate the use of these assets, assure there is no energy arbitration, and avoid grid reinforcement.

The regulatory needs are related to the use of smart meters to directly infer the state of the systems, including the power injection and absorption, which means they can observe how the customers are behaving even if the smart meters are not implemented in each house. An important issue is also the regulatory board about how the costs of the fractions will be divided between distribution and transmission. All these assets allow the operator to deal with the balance of the power flows, meaning the transmission system is going to be applied less in the future and to whom this cost will be distributed.

1.4.3. Service Layer of Smart Urban Energy Providers

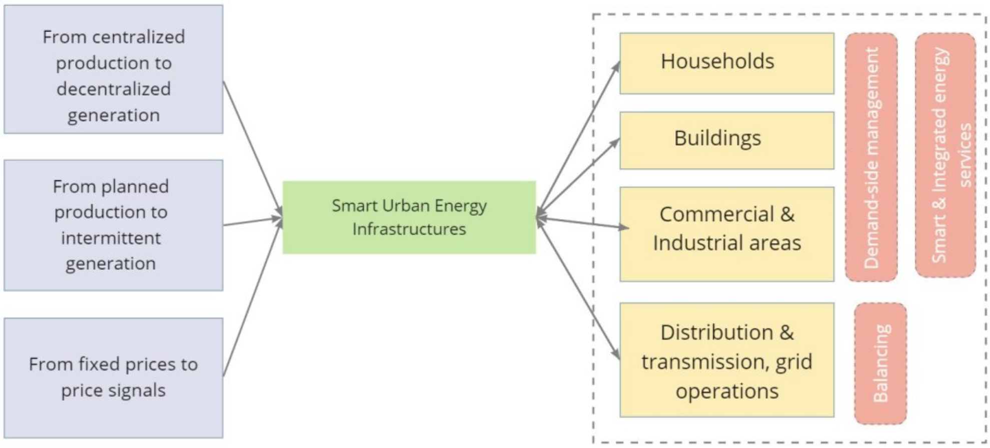

Figure 13 – Smart urban energy service layers

There are four types of smart urban energy service customers: households, buildings with all households in them, and commercial and industrial areas like, an airport or a shopping mall. The fourth type of customer is distribution and transmission system operators who buy balancing energy. The energy that these operators buy is to keep the grid stable. Some services relate to demand-side management; these services offer managing the demand of electricity of households, buildings, industrial areas, commercial etc., to gain more efficiency concerning price signals. In a broader view, there are also smart integrated services and urban energy services. These services link electricity systems with other systems, for example, electric transport, water system, waste treatment, recycling systems etc., which need these sorts of integrated smart energy systems.

1.4.4. Providers

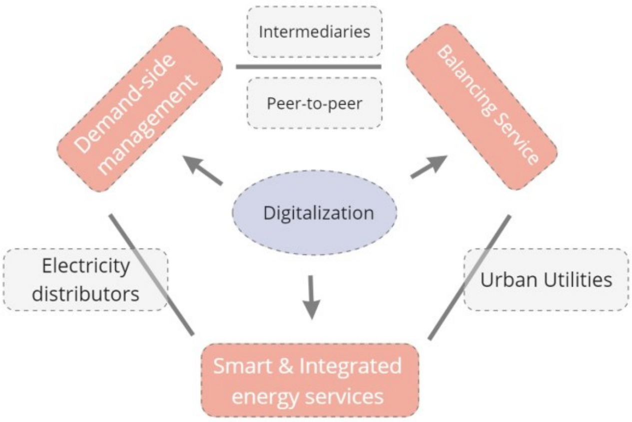

Figure 14 – Smart urban energy providers

Typically, the traditional energy providers are the electricity distribution companies in a city. They can offer demand-side management to all different customers. They offer smart and integrated services by venturing into others as waste, transport, commercial, etc. These services are provided through legacy operators. Urban utilities are services from companies that generally are not traditionally in electricity, in the urban electricity business, but they are in urban water distribution, urban waste management and urban public transportation. They can offer integrated energy services and balancing services by linking customers' consumption patterns to energy consumption. Other providers are the new ones called intermediaries. Those operators are not in the urban business, but they produce devices or possess information like telecom operators, communication, and information operators. They can manage consumption and sell the services to customers, industry, and balancing energy companies. These companies, besides their different business model, also collaborate with the peer-to-peer operators. In all these areas, these services can be provided by new businesses and new operators to the city.

1.4.5. Energy System Data Layer

Data are generated from three primary sources. The generated data create the user behaviour, data from available electricity or energy producers' behaviour where the amount of produced and consumed energy is considered. The most important behaviour is the grid's behaviour, the data generated from the distribution grid. These data are considered as a function of user and generator behaviour. Based on these data, there are smart urban energy services providers. Two different ways are considered in using the data for different services. The first approach is the integrated data where services are provided based on this data, and some companies that access infrastructure use the data generated to provide services. Companies that have or own this data tend not to share those to compete with each other. The second is the approach of data platforms when different data are generated and fed into these platforms. The service providers access these data from platforms to offer different types of services. In such cases, these models raise the problem of regulating competition and ownership rights without having monopoly tendencies or market distortion.

1.5. Smart Urban Transportation Systems

Three main drivers push forward smarter urban transportation systems; the first one is undoubtedly urbanization. Cities are being crowded with more and more people living in, and transportation is being more congested. This has led to an increasingly poor transportation experience, whether by bicycle, car, or bus users. This first drive is one of the main that pushes forward the development of smarter transportation systems. The second driver is digitalization which enables the real changes that lead to a smarter urban transportation system. The third is climate change and resource efficiency. Nearly 15-20% of the global CO_2 emissions are generated from urban transportation, so there is a strong need to make these systems more efficient and make them smarter.

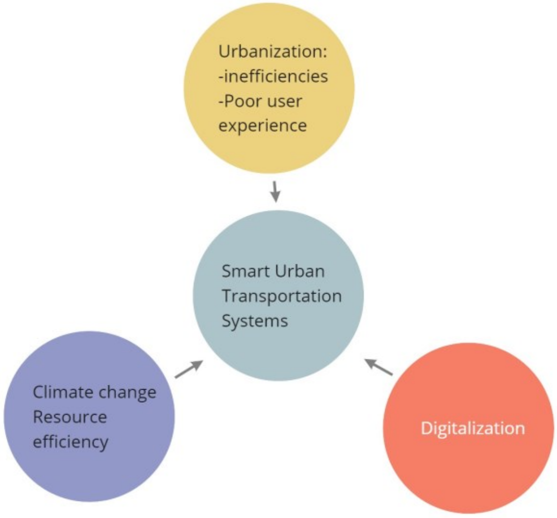

Figure 15 – Urban transportation drivers

More and more people are using cars, and at some point, this overload led to a poor user experience, and the urban transportation systems started to decline. With digitalization, there is a paradigm shift that goes to two elements. The first is that people are willing to own fewer and fewer things, including cars and transportation means, they are more willing to use transportation modes, so there is a disbalance of ownership to users. The second element of the paradigm is that we are moving from separate transportation systems to mobility systems, which means systems are arranged and modified to become a user so that one would care less about the kind of transportation you use.

Thus, this leads to several mobility kinds of services. For achieving this transition, there are two main steps. Generally, there is much improvement in the existing transportation systems, infrastructures, and services, by implementing the new data layer and digitization exponentially increases. That is the first step toward transition; the second step is toward the shift pathway. Things are done in a paradigm shift—ownership versus users considering form transportation mode to mobility mode to mobility services.

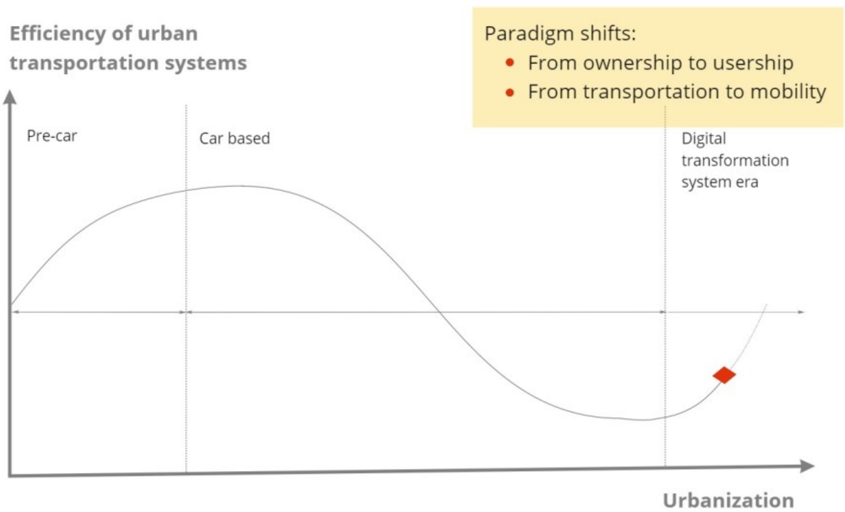

Figure 16– Urban transportation efficiency system

1.5.1. ICTs Improving Urban Transportation Systems

ICT can improve urban transportation systems in two main directions, in terms of user experience and safety, more precisely on how the information and communication technologies are used to monitor urban transportation infrastructure and automated driving vehicles. Two main directions are impacted, there is public and private transportation. Firstly, digitalisation can impact urban transportation systems by making the transportation infrastructure equipped with data gathering devices, such as video cameras, speed cameras, sensors for traffic detection with infra-red, laser, RIFD, and wired and wireless communication devices. With all these, we can have a clearer view of the behaviour of urban transportation systems. This process makes it easier to optimize them accordingly and monitor transportation infrastructure.

The ICTs role in monitoring the transportation infrastructure is significantly linked to the infrastructure layer, so it becomes necessary that managers be more attentive to integrate and link the legacy of the transportation infrastructure with the new data infrastructure. Other Implications are on the data layer, managers' role in paying attention to the accuracy of data, or whether they are complete and holistic is crucial. Data confidentiality processing in the right accountable entities is also a point of sensitive importance. All these data that are gathered to automate and optimize services should not be misused or shared without approval. All these have implications in the service layer, and they can make it more accessible, performing, and respond more adequately to the demand. Private users also can benefit from these new services, e.g. they can change and adapt routes while driving thanks to dynamic route planners that use real-time data. The increased development of self-driving vehicles is the other way to improve the experience of private and public transportation users, the same as urban transportation safety. Nowadays, most road accidents are caused by human errors, so having the machines complete the whole travel transportation reduces the number of accidents, increases safety, and makes urban transportation systems more effective. So the time spent on driving tasks would go in favour to do other tasks and reducing time.

Thanks to ICTs, all traditional vehicle problems, such as direction, stability and control, location, brake status, hours of operation, and so on, are now automated and are progressively moving towards self-driving vehicles. According to the United States Department of Transportation, car automation is divided into five stages.

Level zero is known as a no automated, so it is not considered a proper level. Level one is the first step when the driver benefits from one driving assistance system such as a brake system. Level two is considered where the driver benefits from at least two assistance systems, e.g. cruise control and brake system. Whereas automated mechanisms support these three primary levels, the following three are supported by ICT facilitating the process. Level three is defined as conditional automation, where an automated driving system completes the driving task, and the driver is expected to appropriately respond when needed. Such systems are used generally on highways. Level four is defined as high automation, which is the evolution of the third stage. Here the human driver does not even need to respond when required. This stage is still being developed. The last is complete automation, where all aspects of driving will be done by assistance systems, including activities such as parking. Automated vehicles of level five will not have options for human driving.

These kinds of vehicles fully automated have implications in infrastructure, the data and the service layer, and in order to achieve these levels of automation, the transportation infrastructure needs to be updated and constant improvements. Firstly, vehicles need to be equipped with data processing and communication technologies to communicate and operate with each other. That is known as vehicle-to-vehicle communication. Also, the infrastructure needs to be able to communicate with these vehicles, e.g. speed limitations, road signs, traffic lights etc. Implications in the data layer are also significant; data needs to be standardized between different vehicles, e.g., busses, cars, and other types of manufactures. Another issue of importance is the security of data, who owns them, whether those would be manufacturers or other parties. That is a very sensitive case as it directly impacts the safety of the transportation and the accidents risk.

The social implication is also crucial on acceptance of this kind of automated transportation by public transport. These driver-less vehicles will also have other institutional implications, and the authorities must evolve new driving codes and regulations.

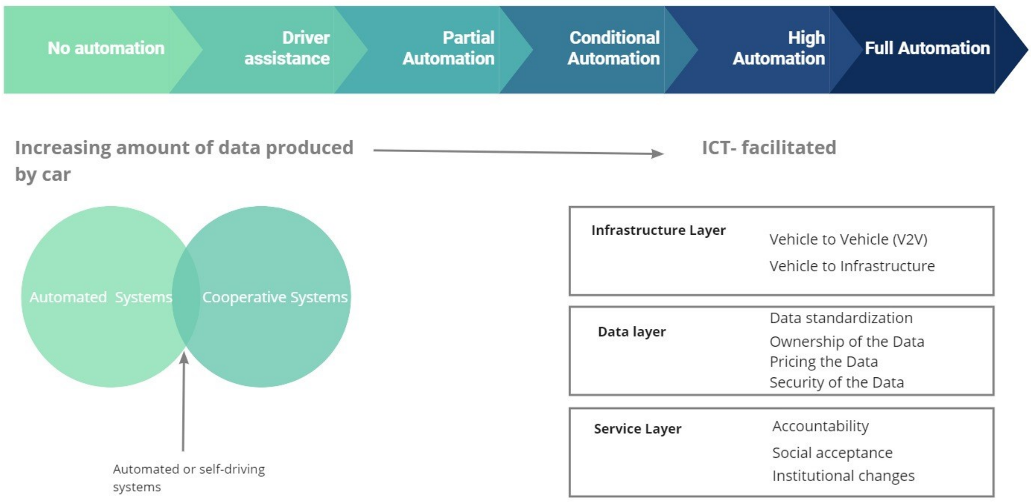

Figure 17 – Automated & self-driving vehicles

There is a constant need for everyday growing population mobility in cities, which is essential for urban infrastructure management. The growth of self-driving cars, new mobility services, and the sharing economy has significantly impacted urban mobility. Modern information technologies enable new modes of transportation and change while also improving the existing ones. An example can be the floating cars that are paid in minutes and can be dropped anywhere, bike-sharing through apps, and many taxi apps that are changing the way of the old taxi services.

All these intermodal transport changes travel without interruption in an easy transition from one transport mode to the other, e.g., schedules are synchronized, or the information about when the travellers arrive, ticket schemes and payments are also integrated. Automation in mobility is undoubtedly becoming a reality. Public transportation as urban rail, underground or light rail trains will still be essential in cities transport mode, creating the transportation backbone. New self-driving vehicles will offer first and last mile transport in intermodal trips. Considered as a non-expensive infrastructure, self-driving capability can avoid traffic jams and be more intensely used than normal by today's cars. They can park themselves, so some other effect is that less parking infrastructure will be needed.

The key drivers for these mobility services in cities also mean connectivity, where the internet of things plays a big role in connecting vehicles, bikes, traffic lights, signals, mobile internet, and smartphones. Such an example is that people can locate themselves on the map and find mobility services around to purchase public transportation tickets. Cloud computing also plays a vital role because now computing resources can be provided in a flexible way. This allows to adapt computing resources when needed, in the morning and peak hours, more computing resources may be needed than in the late-night hours. All these can be performed through artificial intelligence as an important technology, which is essential, e.g., for self-driving cars, helps to improve coordination for complex transport networks. Other technologies such as better and cheaper batteries are also improving.

Meantime, local city governments are also raising the issue of the proper regulatory framework for all these new transport modes. A lot of services can be used; car sharing is another example of how the car-sharing provider will be allowed to park their fleet, which can contain a significant number of cars and in what conditions are these cars allowed to park on public roads etc. Companies are experimenting with another method to regulate their employees' mobility behaviour; they are charged with parking fees for parking their cars on company premises or sites and are given money to subdivide alternative modes of sharing transportation.

1.5.1. Transportation Operators-Innovation Business Models

By 2030, more than 60% of the world’s population will live in urban areas, representing a new challenge for urban mobility systems. Financial sustainability, environmental challenges, and infrastructure capacity are other factors that put the urban mobility system under pressure. A lot is also dependent on dwellers’ habits and needs. Customers want on-demand, customized solutions to their needs. They look for the best value for the money spent, more and more they prefer to pay as they use the system and expect to have additional services and they want to choose their transport solutions at every step of their user experience.

That is the middle time of a fundamental digital transition revolution, and there is a massive range of possibilities for implementing these technologies in future urban mobility: big data, machine learning, the internet of things, the user experience, user interface design, open data and blockchain technologies are just some of them. There are six main models of business emerging. Thanks to the internet, there are intermediation platforms that allow direct transactions between service providers and users. The revenue model is a commission based on each transaction for, e.g. Uber, BlablaCar and Booking.com.

Pay as you use model defines a new paradigm; there is an increase of interest instead of owning a product or asset in the transportation sector. Newcomers are every day coming into sharing-transport cars, services and consumers pay a monthly fee according to usage. Device centric models are based on consumers willing to have top of the line innovative brands such as Apple or Tesla. The primary revenue is the device itself. Additional revenue comes from paying for services within the core system. Low-Cost models focus their expectations on clients for the best price. In this case, revenues come from core service prices. Data-Centric models are now based on process data; they provide customers with free high-quality services and, in exchange, get all the data produced by their use. If it is free, then that means the product is the users. The most representative and developed centric model is Google, the best example of free services in the whole mobility value chain with maps, live transit, Waze, Google Wallet, Google flight, etc. The most recent revolution on the decentralized business model is blockchain technologies which can radically change the business model in the transport sector.

These emerging business models are changing the urban mobility ecosystem; they are changing all the value chain of public transport and are putting more innovative ways to meet urban mobility infrastructure challenges. City habitats are served with customized on-demand mobility solutions. The need for innovative smart mobility solutions represents a great possibility and challenge for legacy transport operators; this means embracing a new digital transformation plan in customer experience, employee experience, operational performance, data IoT, and environmental performance. The need for legacy transportation systems for innovation is to accelerate market innovation, increase agility and speed of execution. The new model business implemented to the legacy operators has increased visibility in the urban mobility ecosystem and established new model partnerships.

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2. IOT SYSTEM ARCHITECTURE

Software architecture and application architecture that satisfies specific software requirements are built through different techniques. Design, evaluation and validation of whether the designed architecture is relevant through smart IoT and AI systems are needed for software architecture and application architecture.

2.1. Architecture Importance in IoT System Development

In many software systems, requirements are first analysed, and many functional requirements are converted into use cases. Use cases are applied in combination of inputs and corresponding outputs from the user viewpoint or a corresponding external system linked to the system. A typical analysis design method usually analyses interactions among elements realizing functionality for each use case. A set of functions realizes a use case; this makes it possible to find appropriate elements in a system, specify mutual interactions between them, and realize functional specifications. Some object-oriented analysis design methods follow such rules. The way of implementing each function is determined based on design.

The use of case-oriented analysis and design approach is an essential development, but it has its problems. Firstly, parts of the system are analysed and designed for each use case, then a whole schema of the system is constructed by merging the parts. This is an approach that is used by integrating the results of the analysis of each use case. However, the modularity of its structure is not considered, and that makes it difficult to clearly divide a system into packages.

Secondly, it tends to have tight coupling and complicated messaging. For implementing these functions, especially in IoT systems, a network system must be created by combining various technologies such as edge, cloud and user as terminal. Components can be implemented easily if the system is divided into appropriate module designs. It can be challenging to build a relation of components between requirements, models, and traceability when this relation is unclear. A key problem is that design models and implementation models usually do not have a one–to–one relationship. So, this makes it difficult to reuse the common parts for each software, and when the function of a part is changed, it makes it difficult to identify its scope of effect. On the other hand, architecture is a model showing a rough structure of a system.

Suppose a system is designed using the logic components at an early stage. In that case, it makes it possible to divide a system into clear packages, so messaging between modules and selecting appropriate implementation becomes easy. Furthermore, when a change is made into parts, standards, its impact can be minimized. The most important thing is the organization of software's overall structure at an early stage of development.

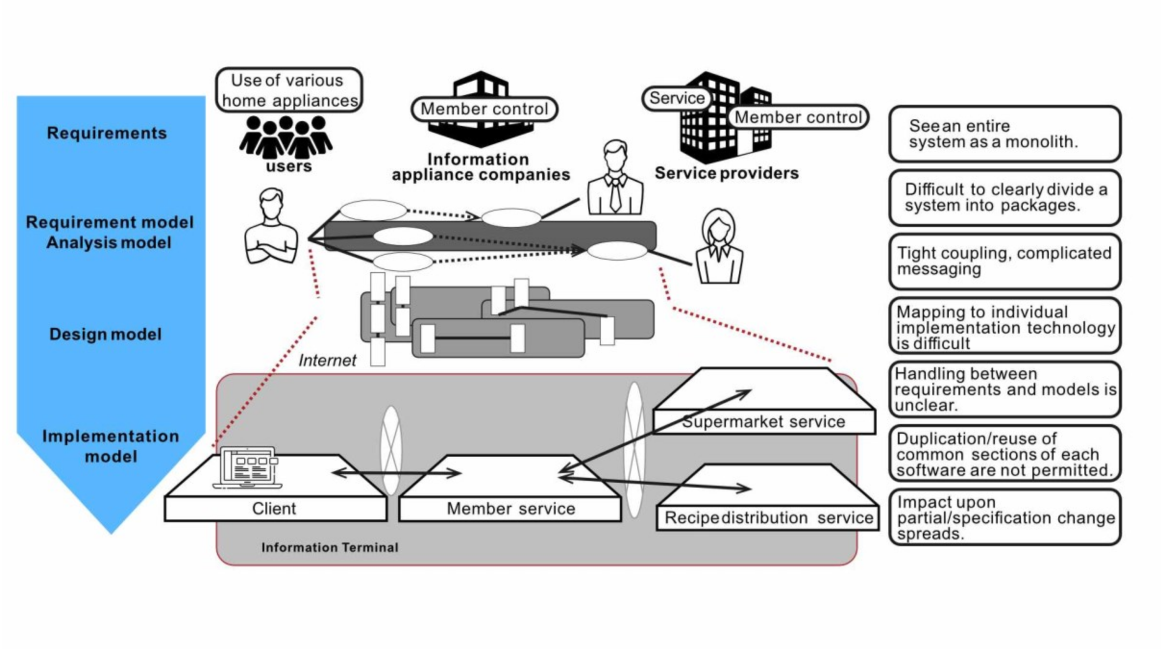

Figure 18 – Software Architecture

2.2. Definition of Software Architecture

Architecture has various definitions, and the definition by ISO /IEC/IEEE 42010 is "Fundamental concepts or properties of a system in its environment embodied in its elements, relationships, and in the principles of its design and evolution''.

Relationships between elements are how the modules are connected. The principles of its design and evolution are rules stipulated upon the creation and modification of the modules. Architecture is to stipulate rules for elements, relationships between elements, design them, determine the system's configuration at an early stage of development, and then stipulate the rules on how to create its modules. A particular quality is obtained for the entire system in case such rules are followed.

Another definition from David Garlan of the Carnegie University, an authority on software architecture. ''The software architecture is a model representing a gross structure of a software system. According to him, architecture consists of elements of a system software, major interaction paths between elements, and characteristics satisfying them''. He uses plain words making the point that the software architecture is a blueprint of the system.

There is a big gap in code implementation realizing the requirements directly. Requirements are usually written from the viewpoint of developers and stakeholders; as per the implementations, they are steps to run a computer at the programming language level where a big gap is between these steps to run a computer and events that are required in the real world. Architecture is used to determine a rough course of direction to realize a system.

2.3. Architecture of Netflix

Netflix is a company that provides mainly video distribution services. It has more than 600 functions and various devices that can connect to the service, making it not a simple company. The video data Netflix owns more than 2 billion hours at the point of measurement and receives more than 1 billion requests per day. It provides a large, scaled service; therefore, it is extremely difficult to understand how the Netflix system is configured at the implementation level. At the architecture level, one of the methods represents coarse-grained modules and relationships between them.

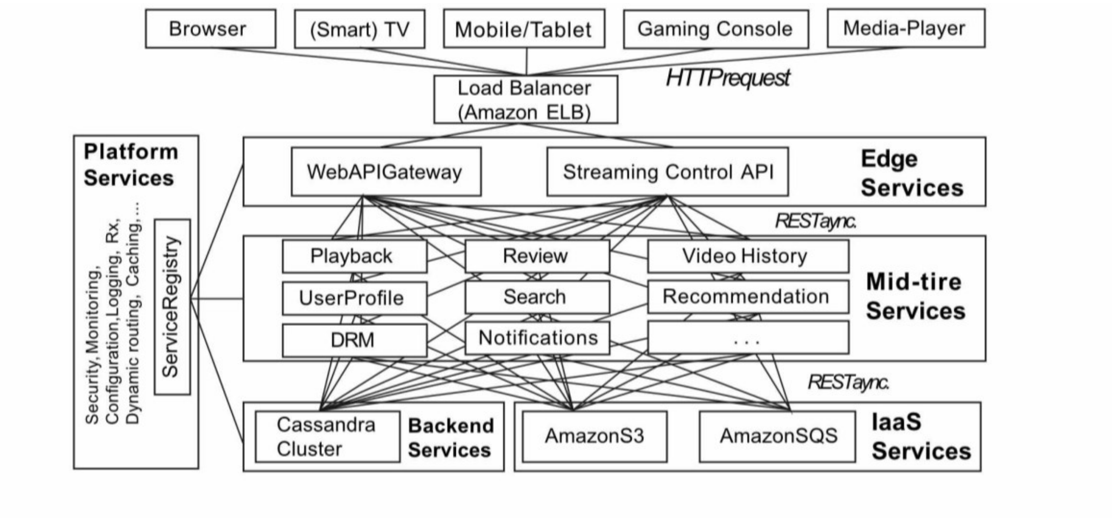

Figure 19 – Netflix architecture software

The architecture is composed of a rough structure of the system supporting various types of client devices. There are Browser, Smart TV, Mobile/Tablet, Game Console, and Media-Player. The devices are connected in a rough structure system to the services at the Edge side; then, they are connected to the Mid-tier Services. Finally, they are divided into the unit where the Backend services' data is stored, the unit where infrastructure data is stored, and the unit of IaaS data. Each device is connected to a load balancer in a more extensive view, and the load is dispersed. Under the load balancer, there are Web API Gateway and Streaming Control API, which provide a function to distribute videos via streaming and a group of functions represented by Web APIs.

Under this tier, Netflix has microservices, and several functions are provided as different services so that each function can be scaled out. There are various functions including, playback function, review function, video history function, recommendation function, search function, user profile function, digital rights management function, and notification function. All these are provided as microservices to scale down by changing the allocation of resources according to the need. High scalability can be obtained. These are in the Backend Services tier, where data is stored. Although a Cassandra Cluster is indicated, this tier stores an extremely large amount of data through a combination of various Cassandra databases. At the bottom, Amazon S3 and Amazon SQS are exceptionally reliable services to store data on IaaS. The architecture also has rules of evolution; the function is constantly used as a newly added microservice from other tiers. If a model is stipulated at the architecture level, it helps understand how the system is configured.

2.4. Software Architecture Roles

Architecture software prominent roles are Understanding, Reuse, Construction, Evolution, Analysis, Management. The first role of understanding helps understand the big system. Likewise, architecture defines upstream constraints on design, such as where data should be stored or where in which tier the microservices should be placed. These constraints are stipulated in a way that architecture helps to understand the configuration of the whole system.

Reuse is the second role. There are architectures that allow components and frameworks to be reused. They can be easily reused and implement existing components to create a similar system. Domain-specific architectures or architecture patterns are encouraged to be reused in these architectures. For instance, the architecture of Netflix can be used by other functions as its functions are provided as microservices which can be used by other services.

The third role is the one of Construction. The architecture is the blueprint of the system. The codes are written according to the rules stipulated by architecture. The entire system can function through connection with other components.

The fourth role is Evolution. Architecture determines the direction of the evolution and how the system can flexibly deal with changes. The appropriate creation of architecture stipulates the evolutionary dimension of the system. In the Netflix case, the structure can be very flexible where the mid-tier services can be increased. This kind of architecture, if organized properly, the evolution direction, the modules can be identified, and the evaluation of cost modification can be done more accurately.

The fifth role is Analysis. Analysis at the architecture level becomes available as a constant check of the implementation of the architecture. Finding bugs at the early stage of development requires much less time and effort than at the test and implementation phase. That is the advantage of finding problems at the early stages of the development, not after the implementation.

The last role is Management. Feasible architectural design is an especially important milestone in development. Therefore, once the architecture is designed, the system must be created based on the architecture, and that also goes for components and subsystems.

2.5. Smart IoT Systems and Architecture

Architecture in smart IoT systems is one of the types of systems, and it can be created by combining different types of technologies. Also, the architecture system is used to create a structure for AI components created from machine learning or deep learning through the data process. Their features are quite different from those of a standard program in which a developer defines and writes rules. For combining such components, there is a need to create architecture for a whole system. A smart IoT system is created in combination with different technologies.

The creation of a machine learning model is not the same as creating a smart IoT system. The creation of IoT devices is not the same as the creation of a smart IoT system. A system must meet a variety of functional and quality requirements by combining various technologies. Likewise, the development of applications on the cloud is not equal to smart IoT systems. There are various combinations of different technologies and various functional requirements and quality requirements for a system. Therefore, in a smart IoT system, it is important to determine architecture properly, identify element technologies to configure the architecture and stipulate the specifications required for the element technologies at an early stage of the system. Consequently, tasks can be easily divided, and redundant functions can be eliminated.

2.5.1. Architecture Drivers

The architect is the person who designs architecture; he determines the gross structure and behaviours of a system using coarse-grained modules. Inputs of architectural design are called “architecture drivers”. They are used to drive the act of creating architecture while considering a balance between various requirements, finding solutions to satisfy them properly, and creating a model.

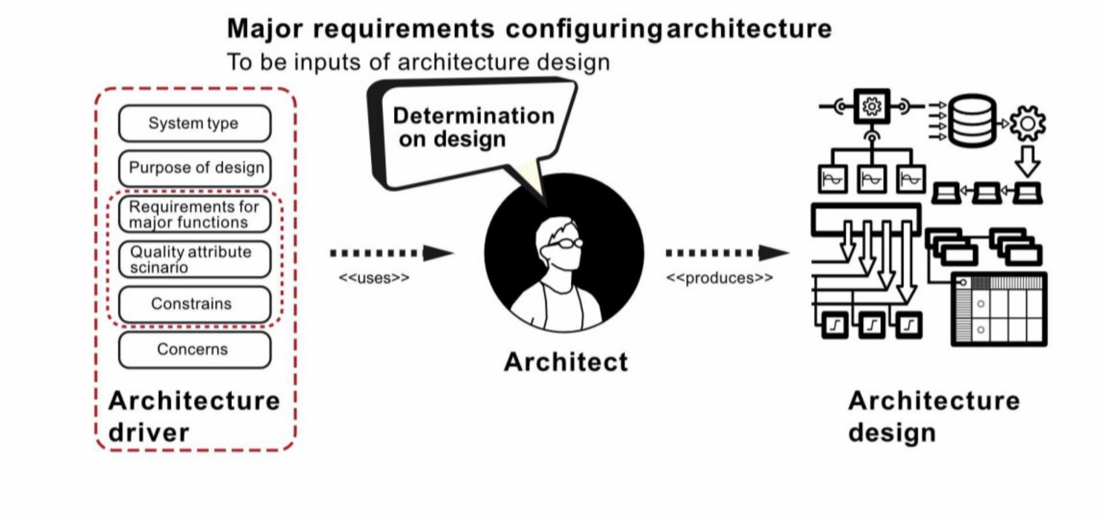

Figure 20 – Architecture software drivers, requirements

Functional drivers or functional requirements are provided by a whole system when required to achieve business goals. Requirements are analysed according to business processes and actual goals. In this way, after business processes-to be, they are presented through a whole system where they are analysed and automated. The processes that are automated are determined through analysis requirement and business judgement. Functional requirements are also based on such analysis. These are the first inputs of architectural design. Another input is quality attribute drivers. They are related to the quality aspect and are more as non-functional requirements. They handle quality attributes that measure characteristics. When handling quality requirements, there are requirements such as performance, availability, modifiability and testability. Another point to be considered is constraints, technical or organizational limitations and restrictions. When a project is carried out, there are cases where implementation technologies already used are determined in advance. In some cases, the customer specifies technologies to be used for the system. In other cases, a development organization determines the technologies used for the project, and such constraints are very important for the elements in architecture design.

The existing constraints might be unknown in a completely new starting business; information that should be referenced for each constraint varies accordingly. That makes that the system type be one of the important points in architectural design. The next point is the architectural design's objectives, which are different and compare the prototype to the ones designed for customers. The last concerns are architecture driver types, which can be defined as decisions on necessary design, regardless of the requirements and goals explicitly stated. Determined functional requirements are easily found by the necessary functions from a customer's perspective.

2.6. Architecture Patterns

When creating the architectural design, past knowledge can be used in some domains. Various reusable know-how, such as effective and excellent architecture examples based on past development cases, can be available. There is know-how focusing on IoT systems as well as general techniques to design good architecture. Design patterns are suitable design methods to design coding and multiple classes. Patterns enable to reuse of know-how in the first place. Design patterns in the software field are known as application forms for the architecture field to the software development. The collection of know-how that suggests what should be used when faced with a recurring problem is called a software pattern. Reference architecture is the creation and usage of one type of pattern or style as an already prepared template using specific domains with past knowledge and effectivity.

Typical Architecture Pattern Catalog/Reference Architecture

General type:

Architecture style: Batch Sequential pattern, repository pattern, interpreter pattern, etc.

POSA architecture pattern: Layers pattern, MVC pattern, Pipes and Filters pattern etc.

Specific type:

Pattern catalogue for data analysis software, AWS cloud design pattern, Azure reference architecture/cloud design pattern, Azure IoT reference architecture, BigClou T reference architecture

2.6.1. Layers Pattern

POSA's architecture patterns are straightforward, classic, and generally used in various places. The basis of architecture is to represent the components a system has and how they are related. The concept of the layers architecture pattern is to express an entire system with accumulated layers of coarse-grained modules. Furthermore, some constraints are added to the layers. The modules are set into layers, and the ones that need less change are set into the lower layers, so the ones that are more likely to be changed are the upper layers. Modules cannot be freely dependent on each other, a module can depend only on the modules of the same layer or those in one lower layer, so they cannot jump over layers. That makes the system more flexible to change; when a change is made, a particular module is modified, the other modules that use that module are also affected. Therefore, when you modify a module, you need to analyse how far can the modification affect everything. However, in the lower layer, the modification is less likely to happen. For this reason, when seeing the entire architecture, a modification affects many modules, but the modification frequency is low. As long as architecture is followed by the rule that modules should be incorporated according to the frequency of change, the entire system is expected to be easy modifiable.

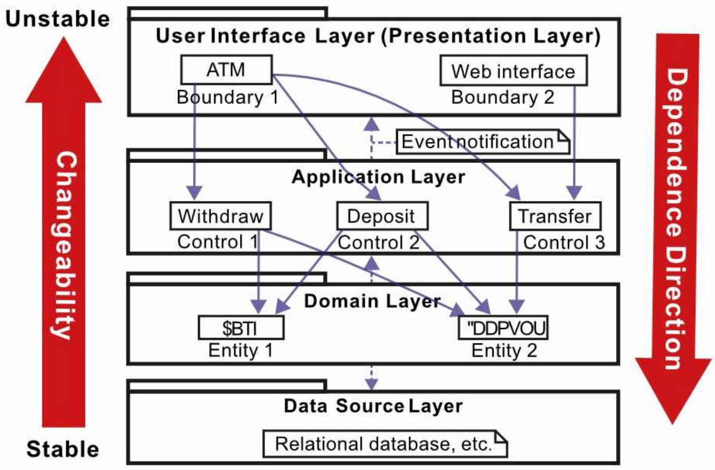

Figure 21 – Layers architecture software

2.6.2. MVC Pattern

Model View Controller pattern (MVC) is basically used for interactive software. Architecture is created using three types of components: Model, View and Controller. This pattern is effective in cases where data has various types of presentations. When data is modified, the corresponding presentation methods and display sections are updated accordingly. When adding or updating a new type of view, it should not affect other modules or the model itself. The MVC pattern is used in cases where the core function data is incorporated in the component called Model. The component provides information to the user called View; the component receives inputs from a user via an input device called Controller. Moreover, it gives a command to View to redraw the data. When View receives a command from Controller, it obtains data from the Model and redraws the data. The MVC architecture pattern provides a mechanism to ensure consistency between Model and UI.

2.6.3. Pipes and Filters Pattern

Another pattern is called Pipes and Filters. That is a pattern to process source input, puts the obtained results into another process, and puts the obtained results into another process again. This pattern is usually used for stream data processing. The purpose is to process data obtained from sensor data in various ways and get results. When the structure is complicated, multiple data sources corresponding to input sources or different data separately processed are gathered at intermediate filters, and then they go through different processing systems. This pattern makes data processing connections more flexible; filters process data and pipes send the processed data. This pattern divides the whole system into Pipes and Filters and makes them combine appropriately. It enhances reusability for each Filter component, and the data processing method can be easily changed according to need by switching the combination of pipes and filters. That is the process of how the Pipes and Filters pattern works.

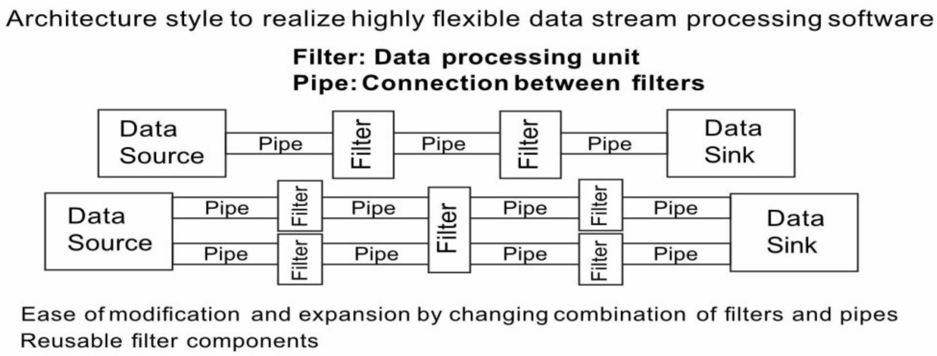

Figure 22 – Architecture software processing, pipes and filters

2.7. Microsoft Azure IoT Reference Architecture

The basic concept for an IoT system is based on three main components: Things, Insights, and Actions. Things is a component where data is created, Insights is a component where business situations are analyzed based on the raw data of things. Actions is a component where specific action on business is taken based on the analysis results. In the Things subsystem, there are IoT devices that are connected to Cloud Gateway, which works as an IoT hub. Various devices collect data, the Insight subsystem data is stored and processed by stream processing, and its results are stored in storage. A function directly displays stream processing results on UI. From the stream processing, there is also a subsystem by combining these components with this architecture.

That is the core of the architecture, and there are more various components according to the product. Microsoft has developed a more refined architecture as IoT Edge Devices. Usually, IoT devices just output data; if a device in which processing is performed at the Edge side is used, computation processing can be performed at the device side. When processing data by stream processing, there are Warm Path Store and Cold Path Store data which is not frequently used. Data in the Cold Path Store may be processed by machine learning at a later stage. The real-time data and other frequently used data are stored in Warm Path Store. The additional components are explained as variations of optional subsystems. These components contain mapping to associate with specific services.

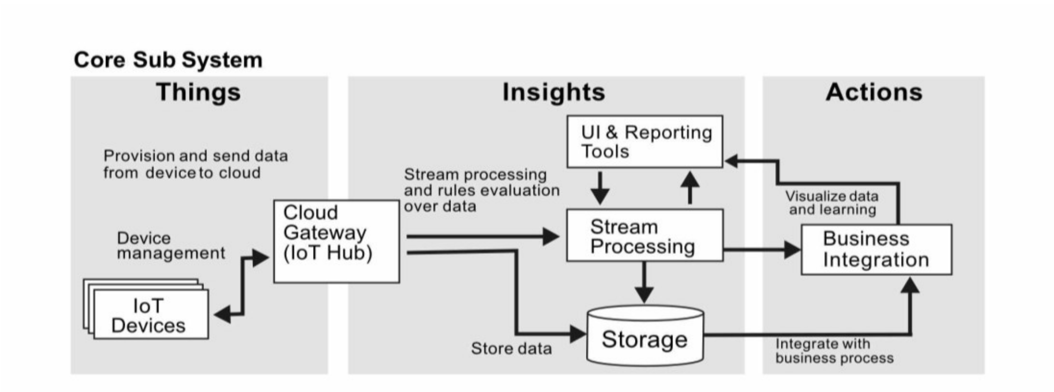

Figure 23 – Azure IoT reference architecture

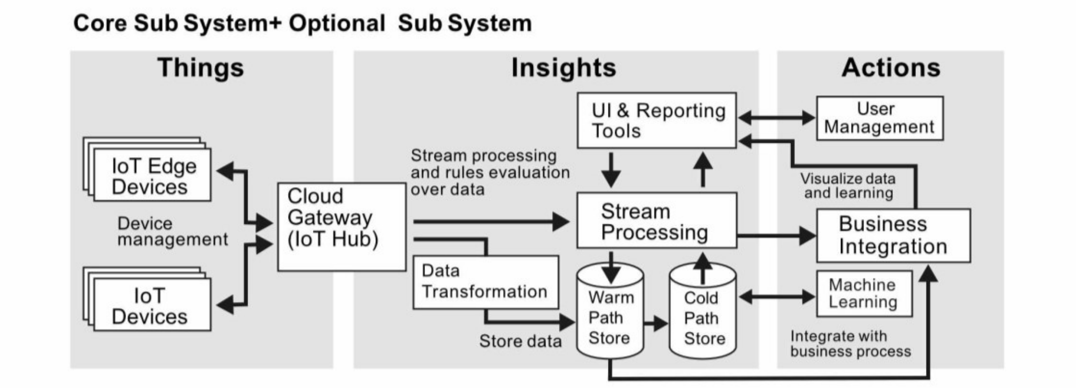

Figure 24 – Azure IoT reference + optional subsystems

2.8. Big ClouT

Creating an IoT platform with various players to take part, various functions are needed that refer to reference architecture for IoT platforms.

BigClouT is an example of a reference architecture used by various organizations and participants which can connect their own devices, applications, and legacy data sets to a platform. There are components that connect them, so everyone is able to use them. Internally, these components can be accessed by standardized API to process data, obtain results using machine learning modules and analyse big data according to need. Moreover, the service can be combined in the platform creating necessary functions for applications.

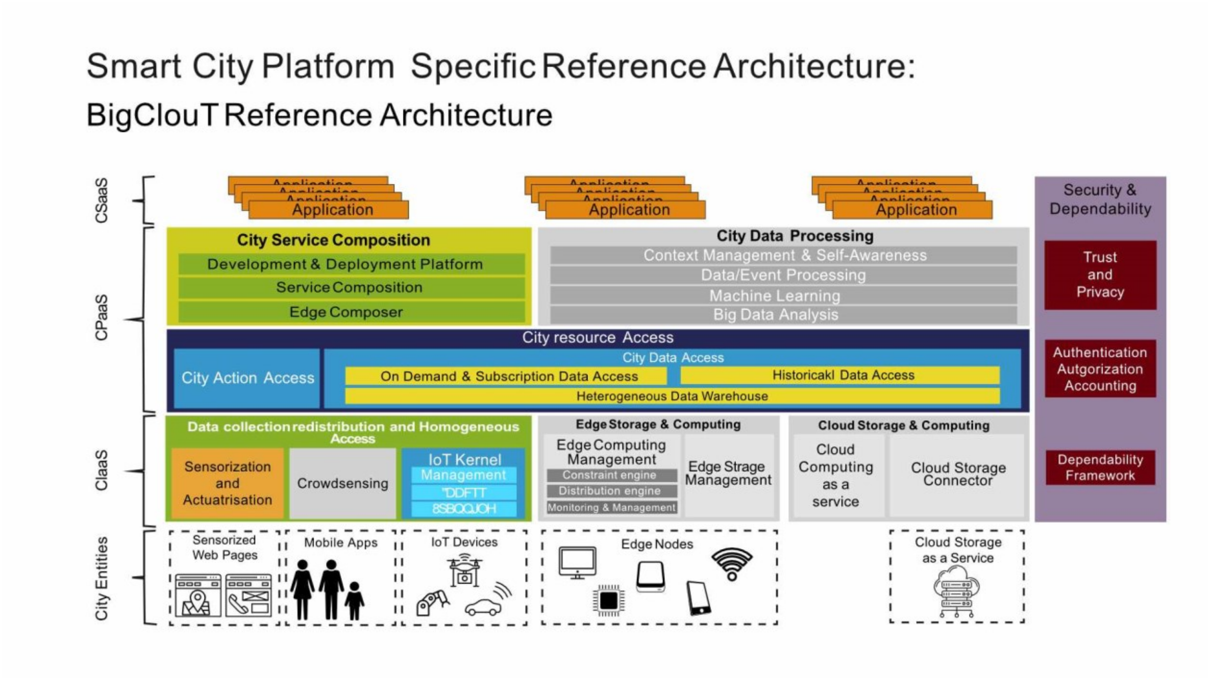

Figure 25 – Smart city platform, Big Clou T architecture reference

2.8.1. Sensors and Indoor Positioning

Indoor Positioning is generally realized through the use of acoustic signals, radio waves, and other sensory information collected by devices. It makes use of distance measurements to nearby nodes, hotspots that calculate the location of the device. The basic concept is the one of set up inside beacons in the indoor environment. These can be receivers of wifi networks or intentionally placed hardware devices tailored to receive radio signals. Indoor networks can actively be positioning the device and send out locational information or passively sensing whether there is a device nearby. However, the complexity of the indoor environment can be challenging as the presence of objects, such as people, partition walls, and furniture, can reflect EM signals, surfaces scatter the waves, or materials may have dampening effects, thereby reducing the strength of signals. Depending on how the Indoor Positioning System calculates the position, such as through RSS,(Received Signal Strength), TDOA, (Time

Difference of Arrival), TOF, (round trip of Time of Flight), PDOA, Phase Difference of Arrival, etc. some may be more inaccurate than others. As satellites do not work well inside the buildings, this makes these systems more valuable for indoor positioning. Wireless Local Area Network, or WLAN, is common nowadays, so, as traditional navigation stops when the car is parked or when the user enters a building or destination, smartphones enable indoor navigation when using shopping mall guides and customer service stands.

This approach is similar to CELL network approach used in outdoor positioning. However, instead of CELL towers and CELL IDs, it uses MAC addresses, the computer's unique identifier or the network interfaces for communication purposes, or SSID, the Service Set Identifier or the network name. RSSI, or the Receive Signal Strength Indication, is a measure of the intensity of signal. Devices will receive WLAN signals nearby and use trilateration or multilateration to determine their distance relative to the access points. The other method is RFID or Bluetooth beacons for positioning. Beacons are pre-set into the environment and can be passive or active. The methodology is the same with the CELL network positioning, using a combination of DOA, Direction of Arrival, signal propagation, signal strength, phase measurements, antenna positions, etc.

Generally, it uses multilateration for the calculation of location. RFID is encountered everywhere in supermarkets that detect when an RFID tag moves outside of the fence. The tags on the goods are passive RFID tags that only transmits a signal near the RFID reader. These RFID tags can be installed on road networks and users can carry an RFID reader, combine the information with other sensing technologies such as a gyroscope, altimeter, and accelerometer; the user can calculate their location based on the last known location of the RFID tag. This tag is a tag-oriented location approach. Both require a connection to a host computer via a network; the signals would be used to calculate the relative location of the device. They are simple to set up, with low cost and high flexibility. The tags can be placed anywhere; this kind of logistics is used in many applications, most notably in logistics retail and agriculture, goods and materials can be tracked, inventory can be easily updated, and staff can quickly locate the stock within the warehouse.

Bluetooth technologies work much in the same way, instead of using individual tags, they use mobile devices and smart devices. Instead of tracking goods, this method is mainly used for interaction between its user and its environment as smart devices can display many different sources of information. The Bluetooth sensors of smartphones both transmit and receive signals to the beacons, allowing the device to report its location and receive information. Shopping malls can then inform their clients of events in nearby stores or send notifications about sales discounts. As smartphones have Bluetooth technology built-in, it allows a wider variety of interactions between the data and the user.

New technologies are starting to be embedded into more than just provisions into light sources, lightbulbs, and fixtures. Other possibilities are explored to make overhead lights to transmit data, and manufacturers have tested possibilities to use LED lights for indoor positioning in supermarkets to provide customers with the latest information and navigation to the shopping list. Locational information is very practical, and the ability to locate a person, vehicle, object or device accurately and precisely is advantageous in everyday light.

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3. GIS

The first-ever recorded GIS application is by French Geographer Charles Picquet in 1832 to represent Cholera epidemiology, where Parisian districts were represented in halftone colour gradients. The power of GIS, even in its earliest form as an analogue map, was made more evident by English Physician John Snow in 1854. During the Cholera outbreak in Soho, London, the forerunning theory regarding the spread of Cholera was the miasma theory. This meant that the disease was caused by pollution or noxious gas. However, observations by John Snow had countered the theory, which led to his investigations into other sources of the outbreak. His investigation in the surrounding Soho area led Snow to believe the source of the Cholera outbreak was the local public water pump serving the area. Using a dot map depicting the deaths around the area, Snow was able to understand the relationship between the location of the water pump and cholera cases. His results led to further investigation on the quality of water at the pump, which was found to be contaminated by bacteria leaked from an old cesspit. Although Snow's work was not the earliest, his work was the most influential to the identification of the science of epidemiology and is a standard in the use of maps for the geographical representation of epidemiological investigations.

With technological advancements, analogue data were digitised, and computers were used to make detailed analysis between location and data. The first computerised GIS was developed in Canada between Dr Roger Tomlinson and the Department of Forestry and Rural Development of Canada in 1962. The Canada Geographic Information System (CGIS) was part of a large scale project for inventory and mapping of local forest and land use. It is built to classify and map the land resources of Canada to enable strategic planning and efficient use of a resource. Though its creation was not without obstacles (DeMeres, 2009):

Although computing capabilities have improved over the years, with the modern-day calculator having more computing capabilities than the early form of computers, the problems encountered by the CGIS are still relevant today. The integration of sensors into the environment has created Big Data, which is a large volume of data using various sensors to record everything happening inside a city. Management of the data, including privacy, protection, access and editing of such data, is still a complex issue. Limitations to computing capabilities may have been removed as the overall processing power for computers more than doubles every two years. And with the invention of the Internet of Things, storage and access are no longer restricted to the physical location of the computer. Whereas computer programming was restricted to computer scientists back in the early 1960s, recent programming languages were created with higher flexibility to allow GIS users to customise the software to suit their analytical needs.

3.1. GIS Role

GIS stands for Geographic Information Systems; it comprises the hardware, software, human-ware, and data. It is a system for acquiring, storing, manipulating, and displaying spatial data. It enables visualization of the data to help with the understanding and analysis of patterns and relationships. GIS hardware runs software which can be a computer or a smartphone. The computers can be standalone or connected in network communication. A lot of software choices are now available, from those of off-the-shell programs to open source for free.

Such software provides tools and functions that store, analyze, and display spatial information. The data gathered or processed is the most important component in GIS. This is expressed in the amount of importance the data take; it reaches around 80% of the overall cost in a GIS project. These data can be developed, purchased from a commercial or government data provider. The human-ware aspects are the people using, managing, and developing the system. These can be technical specialists and GIS analysts that help design and maintain the system. They make use of the system to run queries and perform everyday work. GIS compares the information to see if and how they are related to one another in cases where pollution or population is most concentrated or where the marshland areas due to urban development are most risked. GIS makes use of any information that includes location, which can be expressed as by latitude and longitude coordinates, address, or ZIP code. Other types of information can be compared like population, income, education level, or information such as land, rivers, vegetation, soil types, etc.

Data input into GIS is broadly classified as vector and raster format. Raster format is a scanned image that can be of a land surface or a whole map represented by an array of pixels. Such information is collected by satellite images, aerial photos, and scanned maps. In the raster format, each pixel is coded with a value indicating the reflectance of the scanned object. A raster dataset defines the space as a series of rows and columns, forming a grid of cells—a matrix of pixels. Data, such as attribute values and coordinates, are stored inside each cell. Points are generally represented as a single cell, lines as a series of connected cells, and polygons as a collection of the continuous cell. Raster data is useful for defining continuous data (e.g. temperature changes, rainfall) and thematic data (e.g. soil type, land use) but not so useful for discrete data types (e.g. roads) (ESRI, 2016). The location and size of the geographic information are inherent in this raster dataset. In view of the scale and resolution, a geographical feature may be represented by one pixel such as a river or a clump of pixels such as a lake.

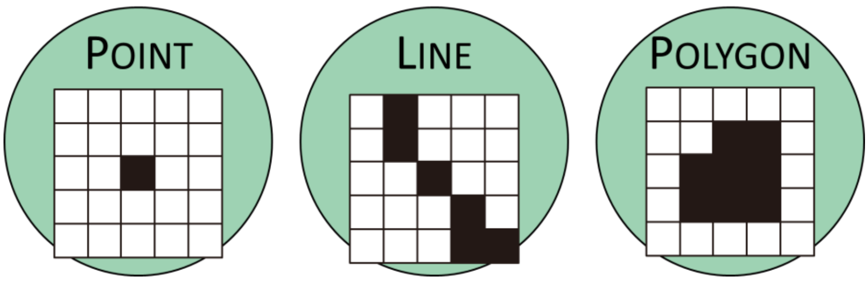

Figure 26 – Raster format

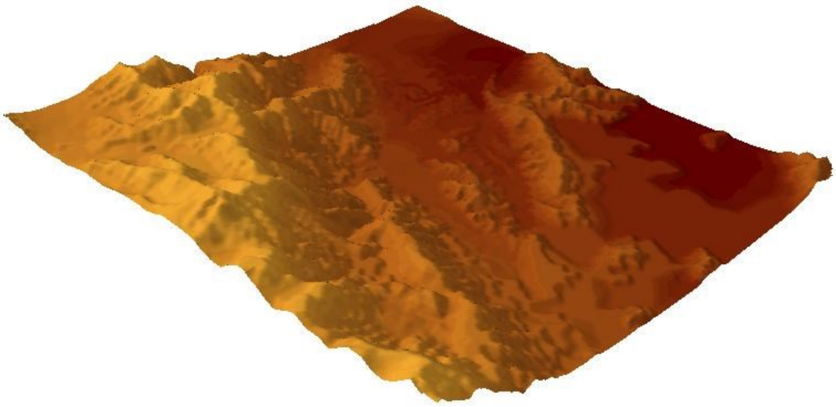

Figure 27 – 3D relief LiDAR scan

Vector form is the digitalization of the selected or interested geographical feature in the form of a point, line, or polygon. Depending on the scale and use of the spatial data, a city can be represented as a point or an area in a vector format. A point on a map has x and y coordinate and a linear feature, such as a river or road, consists of a series of points. Vector datasets store information as coordinate pairs, vertices and paths between coordinate points. The topology, or the spatial relationship between the features, is explicitly stated to map the paths through points. Attributes are associated with each vector feature rather than each coordinate (e.g. line defined by coordinates [x_1, y_1] and [x_2, y_2] and may have the attribute of a road). Vector models are particularly useful for storing discrete data values. With geographic features represented in vector or raster formats, geographic measurements are enabled in GIS software to handle and compute geographical coordinates and angels between locations or points, make deviations on the volume of the terrain or link with other data sets.

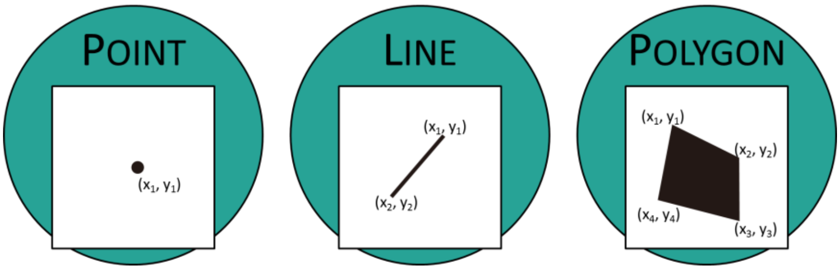

Figure 28 – Vector format

The GIS data comes from a variety of sources that define geographical areas and their locational parameters, such as having an address or coordinate referenced in a system. The geometries and attributes are represented by shapes, sizes and how they have represented the image or the map. Attributes, on the other hand, are identifiers, names, unique codes etc. For example, an attribute of a building can be represented by its name and purpose, such as being commercial or residential. The use of GIS has its own advantages; it allows fast processing of locational enabled data. It can be linked with multiple databases, making it possible to perform efficient analysis that can connect spatially. GIS can easily retrieve the most updated information for analysis and modelling. Users can integrate data from different sources and create a comprehensive picture of their intended location for analysis. The different data integration reveals data integration issues such as different formats and sources that are not compatible with the same GIS platform. This often requires some conversions and the user's constant practice and training.

3.1.1. GIS Software

When people mention GIS, most would immediately think of ESRI and ArcGIS as they are reported to have 43% of the GIS market, a comparatively large market share (ESRI, 2015). However, GIS is more than just software installed onto a machine. Internet services such as Google Map can be considered a GIS if we define GIS by its functionality to visualise, analyse, and interpret data. GIS is a system comprised of 4 major elements:

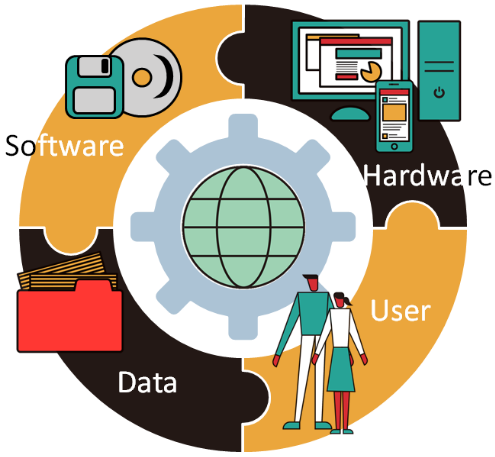

Figure 29 – GIS components

Software: GIS program and supporting programs allow GIS to function and execute. It is designed to organise, analyse, and classify data to answer the user's queries by structuring the data and revealing the relationships inside the data. Commercial software such as the popular ESRI products (ArcGIS) and open source software (e.g. GRASS GIS, QGIS) are designed to support a relational GIS database. The software allows the exploration of Geospatial data, managing and analysing the data, and often displaying these as maps and figures for easy understanding.

The Internet of Things (IoT) implies acts of spatial querying no longer restricted to professional GIS analysts. Web Mapping has become popular, and it allows non-professionals to perform analysis of geospatial information through applications such as Google Maps and Google Earth. (Chang, 2016). The IoT allows for collaborative web mapping such as Google Map Mashups, which allow users to customise the base map provided by Google Maps to create a one-of-a-kind map for displaying information for a public audience. There are instances where Internet Mapping, combined with Volunteered Geographic Information (VGI), is used for crisis management.

Alternatively, users can personalise their maps to plan for holiday trips through route mapping or displaying photos/texts of certain stops to record their trips.

Professional users can communicate between open-source programs and commercial programs through KML files, where data and map layers are converted from the local file type (e.g. shapefile in ESRI) to a standardised file type KML. Keyhole Markup Language is an international standard used to display geographic data such as point locations (Google Developers, 2017). It is based on XML with a focus on geographic visualisation and is complimentary to the Geography Markup Language used to express geographical features (Open Geospatial Consortium, 2017).

Hardware: The physical products/machines the software runs on, can range from desktop PCs to smart devices or devices that help manage the data, such as map digitizers for analogue maps and servers for databases. Their capabilities can affect the efficiency of the software and data retrieval.

Data: These can be in the form of maps, spreadsheet data, images, and textual references. Primary data, such as field observation, sampling, interviews and surveys, are those collected and developed by the intended users. They can be collected by users themselves or bought from data providers. Old analogue data, such as maps, must be digitized into raster or vector formats to enable analysis. The quality of data determines the final outcome of the result, whether or not reliable, and the types of queries that could be asked.

Secondary data, such as census data, are those that external parties developed. Data quality in maps and images is mostly affected by resolution and scale; both will determine the types of data extracted and analysed. Whereas textual and numerical data are mostly affected by sample size and sources, such as data from census or questionnaires. Generally, there is a higher degree of control for quality in primary data sources, and they are subsequently more costly. Data is an important aspect in GIS and can account for the majority of the system cost. Accuracy, precision and timeliness all affect the quality of data. The accuracy determines the trustworthiness of the piece of data, which is dependent on the method of data collection. Precision affects the degree of data sensitivity, how close to the 'truth' a piece of measured data is to reality. Finally, the more timely or more up-to-date the data is, the more relevant the query would be to existing environmental conditions.

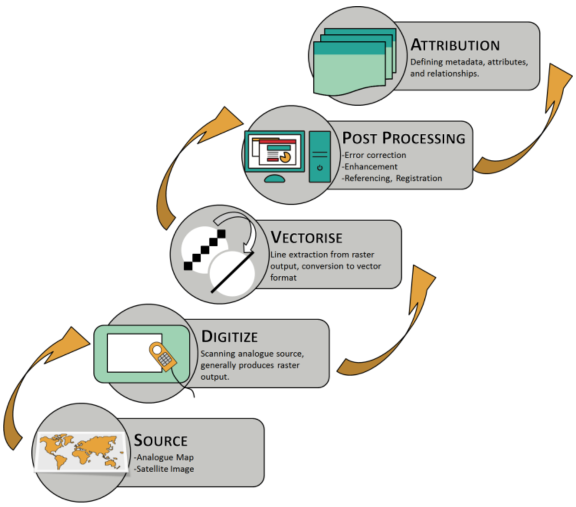

Figure 30 – GIS data flow

User: In the end, it is the users who make the most out of the GIS. The skills and knowledge of the users can affect the types of queries and their output. GIS analysts can make complex calculations with the data, revealing the many relationships and restructuring the data and program to suit their queries. They often possess some computer programming skills and knowledge about spatial data structure, the types of possible errors and corrections required to minimize them or sometimes eliminate the errors. On the other hand, as GIS becomes more accessible to the public, they become GIS users. Simple applications, such as those available on smartphones, are written specifically to address the limited knowledge of the general user. They provide a 'package' function, allowing users with limited knowledge to perform simple searches through existing databases.

3.2. Spatial Data and Analysis

In the form of geo-referenced data, GIS can facilitate much analysis through spatial computing. The geometric transformation between different projection systems retrieves spatial and attribute data from datasets, makes measurements and proximity analysis on features, reclassifies spatial data according to their attributes, and integrates different datasets, terrain or 3D analysis, network analysis, etc. Two basic and common functions are Overlay and Buffer. Land information is arranged in constructing geo-database in different themes and different layers. Land use is one thematic layer, topography or elevation is another, street network, the district zones are some other layers associated with demographic or customer information as attributes. These layers can be in vector or raster formats.

The overlay is to visualize and quantify the spatial relationships between different themes of the same area by putting them together. That is realized by different operators such as union, intersection, difference, subtraction and so on.

Buffer means creating a surrounding area around a point, line, or area feature. For example, the flooding of a river will affect the surrounding area by one km, showing the area where it is affecting it, what kind of land uses, how many people and properties and so on. GIS can do many other spatial analysis, such as terrain modelling and network analyses, apart from the various overlay operations and buffering.

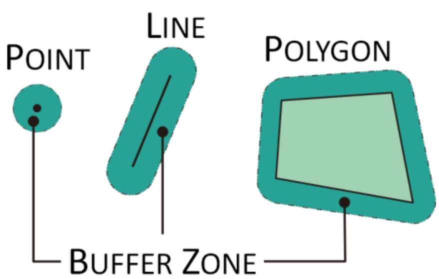

Figure 31 – Buffer functions

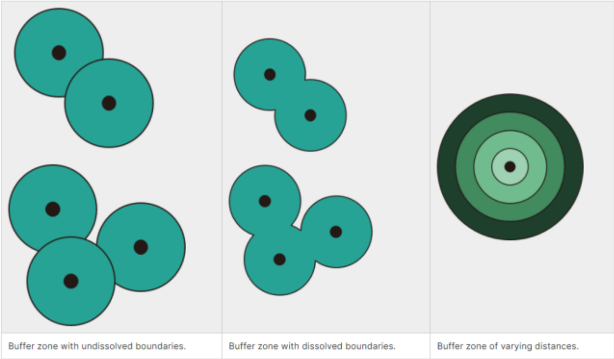

Figure 32 – Circular buffering

Union (A or B)

This operation identifies areas as either one or another of the criteria. It keeps all the areas in the input area and ‘combines’ them into a single output.

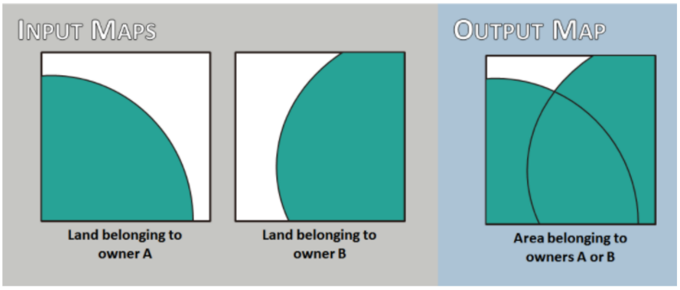

Figure 33 – Overlay union

Intersect (A and B)

This operation identifies areas that belong to both criteria. It selects points/areas that satisfy both criteria.

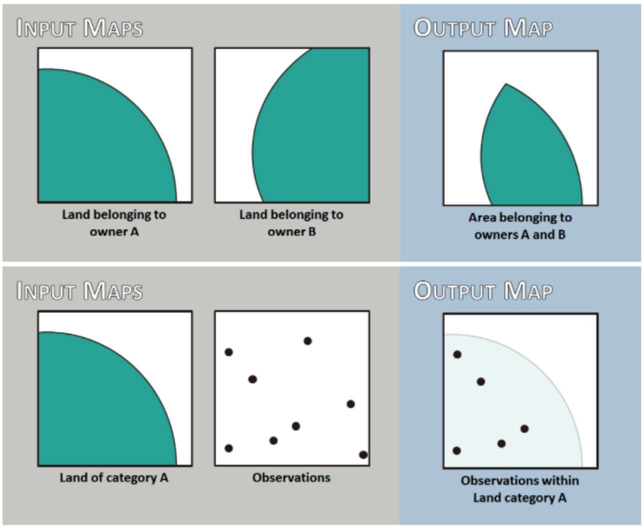

Figure 34 – Overlay intersect

Identify (A and [B or])

This operation identifies areas that definitely belong under a particular criterion with the possibility of belonging to another. It will have the same polygonal shape as the input data but include information from the additional map.

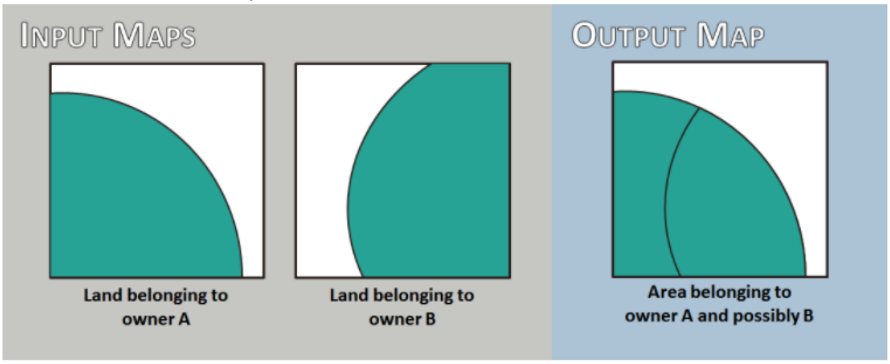

Figure 35 – Overlay identification

The computer allows for the automation of map creation. However, it still requires a human operator to define the logic and rules. GIS software allows the operators to link spatial datasets and databases with a base map for visualization to display relationships between the various spatial elements.

A map is an abstraction of reality, aiming to communicate spatial relations and forms with temporal (time) variations. Maps are scaled representations of real land information, tangible features, concepts, and phenomena. They are mostly 2D, transforming the 3D world into a 2D medium. However, the continuous improvements of technology make it possible to produce maps in 3D and visualize them using hardware such as 3D glasses and immersive environments.

Data sources for a map can include:

- Historical Data: such as previously compiled maps;
- Remote Sensing Data: Aerial photographs and satellite imagery examples
- Survey Data: such as ground measurements from terrestrial surveying and GPS records; and

Documentary information and textual attribute data (e.g. building use, land classification, land ownership).

3.2.1. Mapping Process

The mapping process starts with data collection. Locational data can be collected through terrestrial and GPS surveying, where positions and coordinates for objects and points of interest are collected and compiled. Spatial or locational data can be supplemented with aspatial attribute data. Attribute data is concerned with the 'characteristic' of the object and point of interest (e.g. building and land use, population, etc.) and can be compiled through documents such as building plans or a neighbourhood Master Plan.

Figure 36 – Mapping process

- **Define Map**

Factors like the type of data, style of map, and design are affected by how the map is intended to be used and by whom.

- **Gather Data**

The reliability and source of data are important to produce an accurate and usable map. The source of data can affect the accuracy and precision of the overall map and the subsequent decisions made through the use of the map.

- **Data Selection**

The data selected to be represented on a map is determined by the purpose of the map, at the same time the data can also shape the aesthetics (look-and-feel) of the map.

- **Classify & Analyse**

Generally, the human operator will have to perform classification or analysis on the data to produce meaningful information displayed on a map. Data can be classified through its attribute or through the selection process on the software. As GIS is often used for map production, it is possible to perform spatial analysis on the gathered data and present the findings through a map.

- **Drafting**

That is the artistic element of map-making. However, before production could occur, some aspects of the map should be present: Border, Orientation, Legend, Title/Theme, Scale (or **B.O.L.T.S.** for short). Border is the framing of the map and the grid lines. Orientation is the representation of North (or the North arrow). The Legend should explain the symbols and colours used on the map. Title/Theme should be easily understandable by the users so that the user will know the purpose of the map (i.e. "City Population Density Map"). Scale must be present for users to determine the size of real-life objects as represented on a map.

- **Production**

Traditionally, this means the map would be ready for printing. However, with the availability of online mapping tools, it is relatively easy for anyone to make a map and publish it online to share with others. This online mapping software are generally equipped with tools to insert all the stylistic elements in maps automatically.

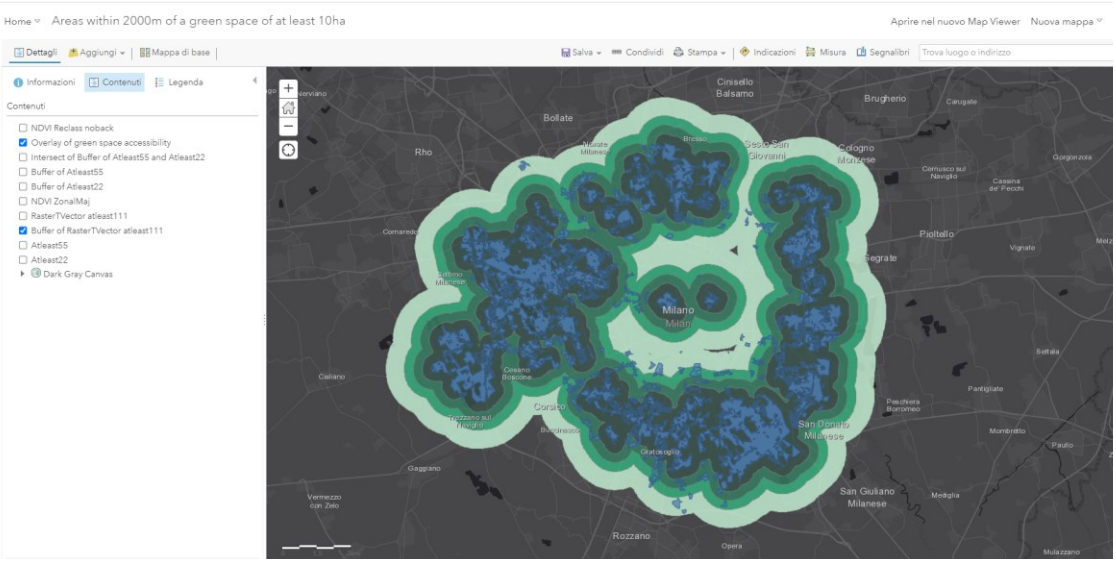

Figure 37 – Milan green space 2000m

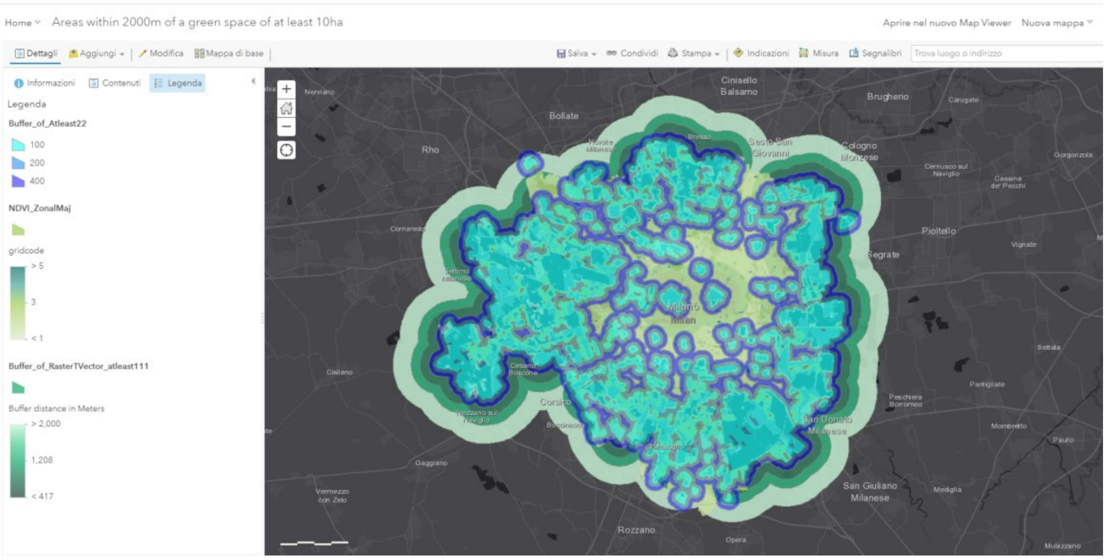

Figure 38 – Milan green Overlay zone

3.3. Application of GIS in Transportation

An issue of concern in an urban environment is also traffic. The planning provision, management of transport, optimization of roads to meet demand, and identification of opportunities for improvements are enabled using Geo-informatics. Apart from the base map of the city, a comprehensive transport database is the foremost important requirement. In addition to land information available from the base map, other detailed information on transport includes a road network of vehicular and pedestrian use. Depending on the varying levels, like street levels, bridges or elevated walkways, tunnels, or subways, there is also other information embedded such as traffic lights, path directions, lane and turn information, the cost of traversing a tunnel or highway etc. All are important to model the flow accurately.

There are different modes of flow on the road network, such as by car, train, public transport, and even on foot; each needs different sets of spatial and attribute data, different patterns of demand, and different transport models. For example, the public transportation system supplies the more preferred routes in terms of time, fare, or mode on many websites and apps. It also shows clearly to alight and board the bus, train, or ferry. Different sets of transport-related information are needed to do this. Firstly, all stops must be captured as points with attributes of bus number, stop name, headway etc. All this can be put in a query about available and reasonable walking distance to be found and how to travel from one point to another. Routs have to be digitalized as lines into an interconnected linear network. Other attributes such as direction, stop sequence, fare and many others must be associated with these stops or routes. Such a comprehensive transport database is not only useful for route finding but also for planning. Adding more data about changing traffic conditions in a day and each road segment makes it possible to identify when and where traffic congestions normally occur. With real-time traffic information, it is possible even to model the arrival announcement system. Travellers' behaviour is another example where areas of high and low demand for routes can be identified, so planning the headway appropriately or if re-routing is needed. Unlike traditional transport simulation, it can handle a diverse and complete set of transport data to generate key spatial information like location, distance, and time. All these transport-related themes can be visualized and understood easily through GIS.

3.4. ArcGISpro creating feature class and entering data

After positioning the map in the desired location, several applications can be performed through ArcGISpro software, which enriches the map with various data that can be edited and improved continuously through different attribute tables. That is a case of creating points representing buildings with different data, digitalizing roads by lines and creating an example of building footprints by drawing building shapes. All this information can be upgraded and enriched over time. Different feature class layers can be created that enable different performance analysis through this data gathered.

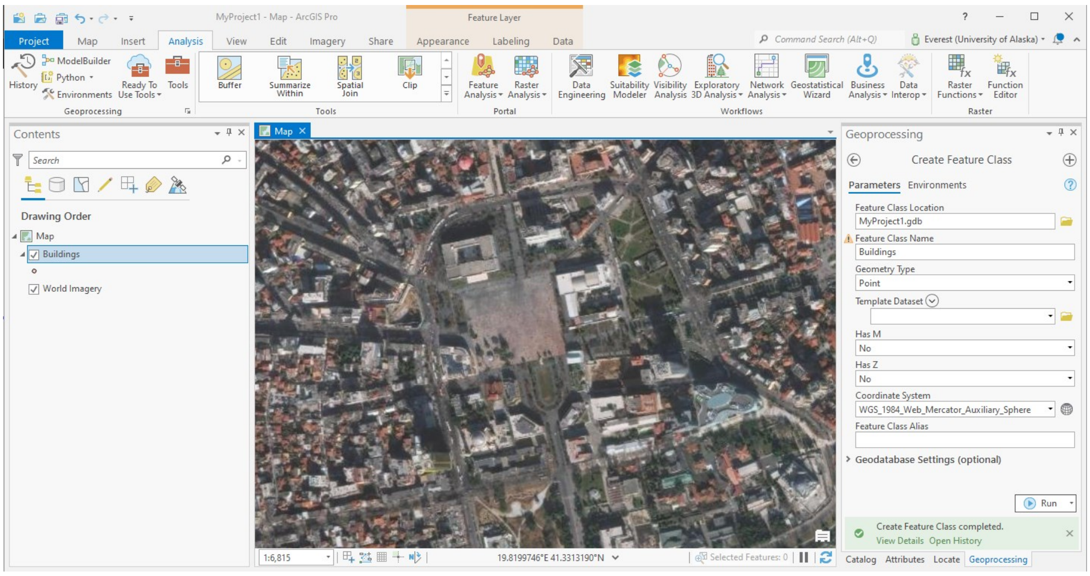

Figure 39 – Tirana Skanderbeg Square point creation of buildings as a feature class

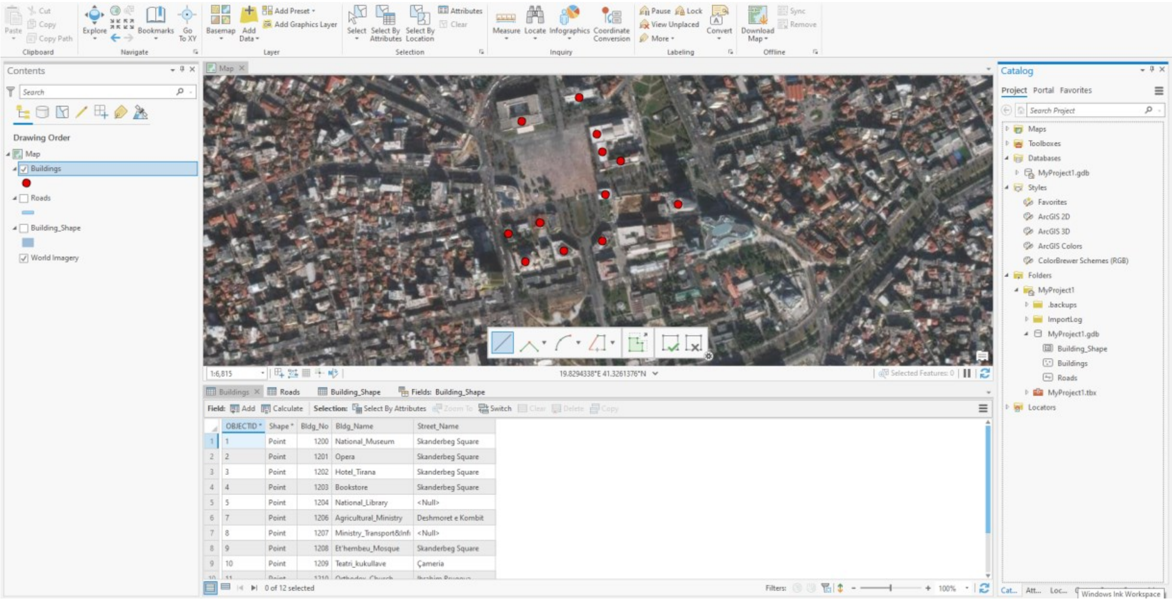

Figure 40 – Tirana Skanderbeg Square, red points representing buildings

As seen in Fig.40, the red points are set as building points, and at the lower part of the attributes table, through selecting the points, a lot of category and information can be inserted for each building as building number, name, street name, etc. On the right part of Fig. 41, various layers of information can be added to the map database. Likewise, it is possible to create and digitalize roads, building shapes and enter and calculate various information in the attribute database chart as area, length, perimeter etc. All these entered data can be used to or selected through different specific criteria for performing different analysis or selections.

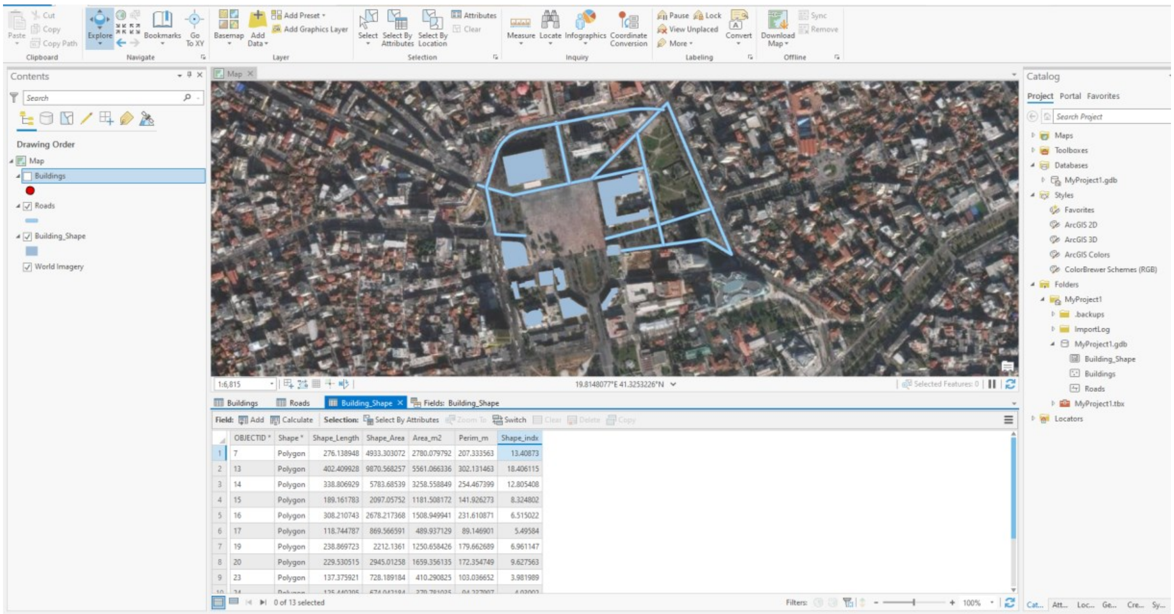

Figure 41 – Tirana Skanderbeg Square road & building footprint database

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4. SUSTAINABILITY

Climate Impacts, Adaption and Mitigation

Climate change has progressed from a relatively unknown issue to one of the most pressing urban challenges we must respond to. It is believed that only 600 cities contribute 60% of world output. Many of these concentrated climate dangers are concentrated in climate hotspots, such as low elevation coastal zones. The poor and vulnerable are also impacted in a disproportionate way by change of climate, and it has the potential to alleviate poverty. Since the nineteenth-century industrial revolution, a variety of new energy and production technologies, particularly those that utilise fossil fuels such as coal, oil, and, more recently, gas, have helped catapult some industrialized countries to high-income status. As a result, the atmosphere has been employed as a massive worldwide sink. There is yet no single factor indication that explains differences in per capita emissions among cities. Population density consumption patterns, land-use mix, connectivity, and accessibility are key urban drivers of energy and greenhouse gas emissions.

Greenhouse gas emissions and atmospheric concentrations have resulted in a 0.72 degree Celsius increase in global temperature over the industrial average. In addition, because global temperatures are not the same everywhere, they translate into greater temperatures in higher latitudes, leading to the melting of Arctic ice. The phenomenon would cause a huge sea level rise, affecting cities along the coast. Human-caused greenhouse gas emissions have gradually increased since the 1970s but have accelerated since 2000.

The majority of this increase is due to carbon dioxide emissions from fossil fuel combustion and industrial operations such as power generation or automobiles, followed by CO2 emissions from changes in land use and methane emissions from deforestation, agriculture, and urban growth.

Over the previous 40 years, low-income countries' gross emissions have altered only modestly. Emissions in lower-middle-income nations have more than doubled due to land-use changes, as well as changes in the energy and industrial sectors. Global urban population expansion in the early twenty-first century will necessitate significant construction of buildings and urban infrastructure, both of which will be major contributors to GHG emissions. The exact factors that enable some of the most economically vibrant cities to prosper, such as strategic locations along trade routes, access to seaports, or river canals, now leave the majority vulnerable to the consequences of climate change.

Climate warming has increased the frequency and intensity of natural disasters, current hazards, such as drought, flooding, cyclones, hurricanes, storm surge, rainfall variations, and rising temperatures.

Climate mitigation is a set of interventions aimed at limiting the magnitude and scope of long-term climate change, typically over the twenty-first century, by reducing greenhouse gas emissions, for example, by shifting to renewable energy, implementing energy efficiency, reducing energy intensity and consumption, and increasing the capacity of carbon sinks, for example, through reforestation or more radical ideas like carbon capture and storage.

Cities offer profound decarbonisation and mitigation by focusing on urban economic sectors with significant mitigation potential, such as construction, energy, transportation, and industry, converting the cities into low-carbon through urban regeneration, development, encouraging transportation, walking, and cycling, building adaptive reuse, and the use of energy-efficient building designs. Other issues of equal importance in terms of decarbonisation impact include better use, planning, and management of land, the development of fuel-efficient vehicles and active mobility, and the effective use of a variety of policy instruments by promoting the colocation of high-density residential and employment areas. This situation can be improved by changing power generation to renewables and lower-emission fuels and integrating photovoltaic and renewable productions from small local networks.

Adaptation refers to several actions taken to lessen the exposure and susceptibility of economic, social, and ecological systems to climate change. That is due to the failure to neutralize, minimize their effects quickly enough. The limits to adaptation, if violated, could bring irreversible consequences for specific systems or locations. Cities can become areas of transmissive adaptation by dealing with increased exposure and vulnerability through ecosystem-based adaptation, increased urban food security, high-quality, affordable, and well-located housing, reductions of basic service deficits, and the construction of resilient infrastructure.

Cities are not simply local climate hotspots; they also provide the chance for rapid climate track, enhanced by the momentum of urban investment, increased institutional capacity, and the potential for social, economic, and technical innovation. The majority of the urban infrastructure that is predicted to be in place by 2050 has yet to be constructed. This means that there is still time to develop appropriate urban solutions that avoid or minimize carbon lock-in. Improvement opportunities are expected with integrated long-term planning as new buildings and infrastructure are constructed and new energy consumption patterns are formed.

Mainly in the world, there are clear limits to adaptation. Cities and regions not only create two-thirds of current greenhouse gas emissions, but they also house half of the world's population and three-fourths of the global economy, all of which are vulnerable to climate change to varying degrees. As we expect a severe climate change period, urban areas are foreseen to be impacted by extreme weather events and related health risks even before rising sea levels and other irreversible changes occur. This indicates that deep decarbonisation of urban systems, from energy and infrastructure to buildings, transportation, and manufacturing, is required if irreversible effects are not to be seen by mid-century. Local and regional administrations, as well as local action, are critical to the effective implementation of the climate agenda in cities.

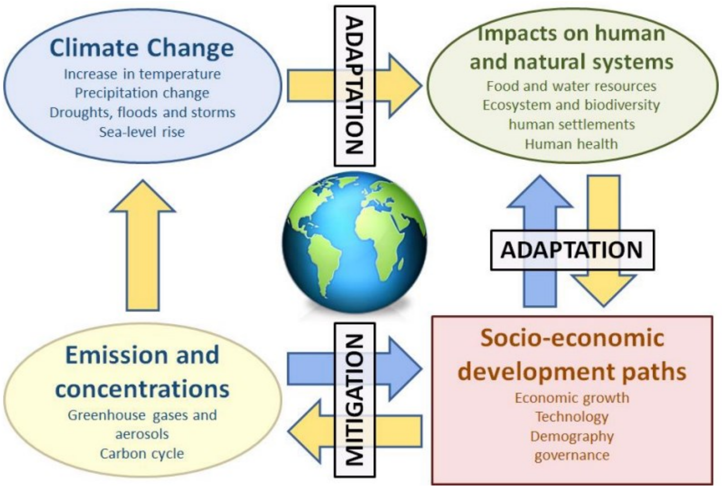

Figure 42 – Climate change Adaptation and Mitigation

4.1. Sustainability Efficiency Assessment

Impact Assessment

There are three main basic elements defined in smart cities sustainable assessment, Sustainable Urban Mobility, development, and design implementation of sustainable districts and then the interest of infrastructure and processes into them. These three main topics have different levels in which we perform our impact, political level, decision level, and understanding, including the availability of funds and different business models.

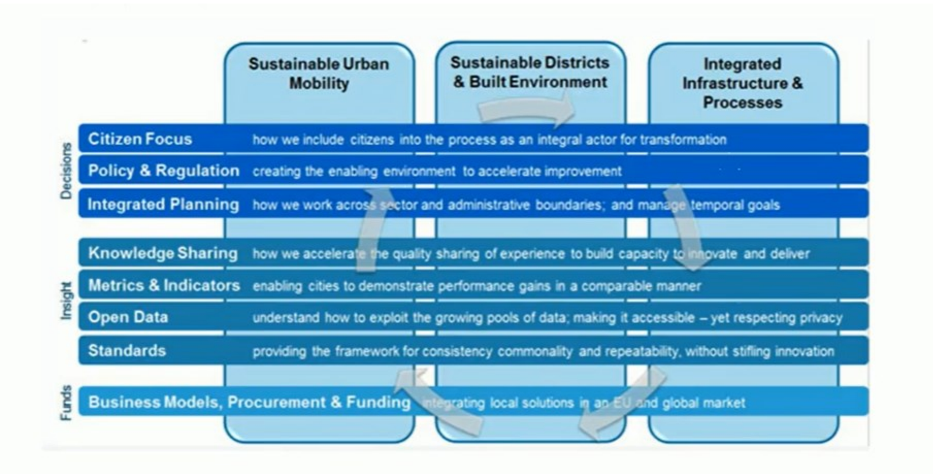

Figure 43 – Define assessment priorities

Once the structure and interconnection of the various problems are clear, the preceding topic is the data widely available through many elements in the city such as road networks, traffic control, parking, buses, sensors developed and introduced by cities concerning air quality, air temperature, and even waste evaluation and different data sources.

The model is equipped with different data through sensors and the Internet of Things. This variety has to be handled to make it consistent for the framework analysis impact according to the sustainable development goals indicators. So, all the levels and layers are measured simultaneously to provide a complete picture of relevant evolution and standards.

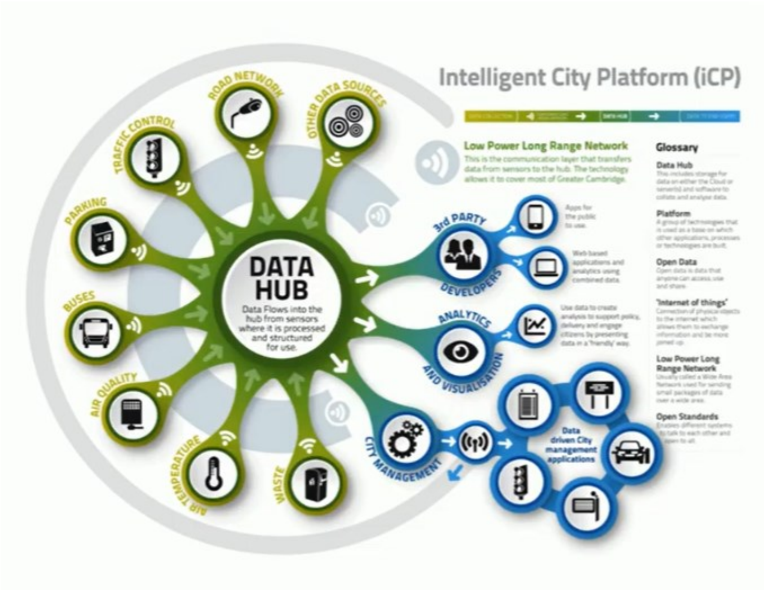

Figure 44 – Data Hub structure

City decision-makers also need models, and they need data projects for different simulations that can finalize combined assessment frameworks. By combining history and the simulation results, it is possible to see how the driving elements or outputs with minimum input consumption can be addressed. This makes it possible to adapt solutions in real-time and know how efficient the policies are and if the money the decision-makers invest in a city can obtain the best possible results.

The expansion of urban settings is linked to global sustainability concerns, particularly in places where the urbanization process is still developing or the urban metabolism is experiencing extensive regeneration [1]. In urbanized regions in Europe, where more than 70% of people live in cities, one of the most pressing challenges is sustainability, particularly in terms of energy use, economic performance, de-carbonization of infrastructure, wastewater management, and other ecosystems from cities and urban communities [2]. The use of these resources can significantly impact the achievement of the UN Sustainable Development Goals [3].

Existing building certifications are the most acknowledged method of linking sustainability to greenhouse gas emissions from a life cycle assessment standpoint. BREEAM (Building Research Establishment Environmental Assessment Method) and LEED (Leadership in Energy and Environmental Design) are two examples. SBTool (Sustainable Building Tool) [4], Green Star, and CASBEE (Comprehensive Assessment System for Built Environment Efficiency) [5] is a comprehensive assessment system for building efficiency. These kinds of certificates, through study, substantially contribute to understanding the environmental consequences of structures methods for life cycle assessment. They may influence customer decisions when purchasing building materials and serve as valuable resources for decision-makers in both developed and developing countries.

While cities are lauded for being engines of invention, social experimentation, and economic progress, they are inherently complex systems with the potential to self-adapt to external and internal forces, transforming them into ever-changing "organisms" with their own adaptive metabolism. In order to confront severe social and environmental issues brought on by unrestrained urbanization [6]. An examination of the capacity of cities to self-organize in the face of constant change can explain the ability of cities to self-organize. Food, commodities, and services consumption, waste management, freshwater provision, and other ecosystem services that measure sustainability, services inside a city's metabolism may be examined as a complex system [7]. As a result, every inquiry or design for a city must examine the network that connects all the sections and their connections to their surroundings, the network dynamics (energy flows, etc.) matter, people, products, information, and resources are critical for comprehending the changing world, the character of cities. The measurement of network efficiency has been used to analyze long-term performance in Urban systems [8]

However, city metrics are accessible and comparable (through ISO 37120 and its wide variety of key performance indicators, called key performance indicators (KPI), the Slack-Based Inefficiency (SBI) Urban Sustainability Assessment provides a more realistic effect assessment approach. Big data-driven ISO 37120 can also be used to define ways for providing finely dispersed evidence, allowing for the suggested technique's future evolution. The efficiency outputs must then be assessed, both from control factors and from their historical interaction, which statistically incorporates many variables. All players' effects are measured using a simple set of key performance indicators (KPIs) [9]. Furthermore, urban, with their limited resources and city planners, has little direction for balancing competing agendas and resources. A Data Envelopment Analysis is a method for imagining efficient alternatives (DEA) of the essential KPIs validated from historical factual data to estimate future simulated performance derived from several policy scenarios.

4.2. District Energy

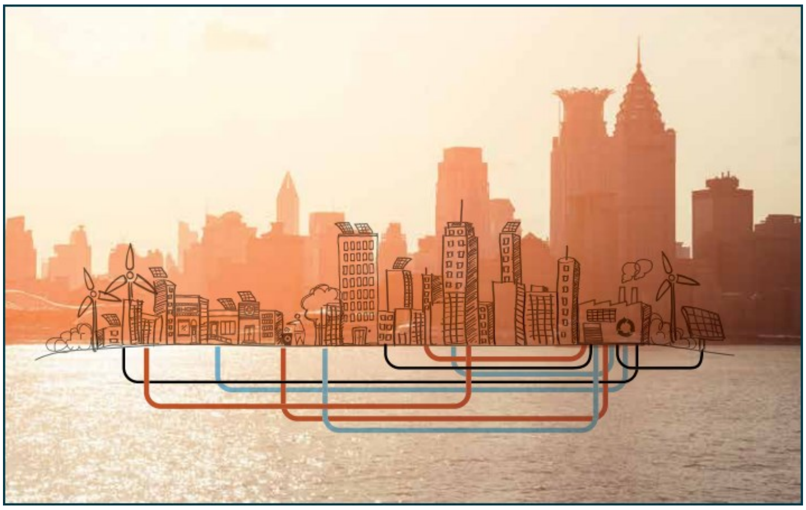

Figure 45 – District energy heating system

Shutterstock technologies such as boilers and air-conditioners consume vast amounts of energy in homes and workplaces, schools and hospitals. Indeed, half of the energy buildings use is for heating and cooling, and most of this comes from fossil fuels, burned in buildings' boilers and power plants on the outskirts of our cities. This enormous shift cuts greenhouse gas emissions, clean our air, saves money, and reduces energy imports. Citizens, cities and countries are starting to take real action to move away from this status quo to more sustainable solutions. They were consuming 70 per cent of global energy, and as managers of local infrastructure, cities provide the ideal opportunity to develop innovative and sustainable solutions to heating and cooling.

The concentration of buildings in cities means solutions can integrate multiple sectors, such as heating homes with underground heat or using cold water from rivers to cool whole neighbourhoods, as seen in cities ranging from Copenhagen and London to Tokyo and Seoul. The citizens of these cities are the first to benefit: fewer fossil fuels means cleaner air, steady heating prices and an easier fight against fuel poverty. Sustainable cooling cuts electricity demand from air conditioning during the hottest times of the day, increasing energy security for millions by reducing rolling blackouts and costly electricity infrastructure upgrades.

Many cities are prioritizing modern district energy as the integrated solution needed for sustainable heating and cooling. A district network energy system comprises underground insulated pipes that distribute hot or cold water to multiple buildings throughout a district, neighbourhood, or city. Some systems connect a few buildings, while others connect thousands of buildings and homes across a city. The result is the same: providing heating and cooling to multiple buildings; district energy systems are able to use far larger sources of heating and cooling than can be connected to just one building. Such sources include waste heat from industry or power stations; solar thermal, groundwater and sewage; and free cooling from lakes, rivers, or seas.

For cities, these larger sources of heating and cooling are greener and cheaper and make them more energy independent. Furthermore, district energy systems take advantage of excessive wind or solar power or surplus heat in the summer compared to other energy storage options. This energy can be integrated to balance variable renewable power through conversion to heat and stored for use seasonally (using soil or water) or during peak demand. Neighbourhoods, cities and countries are increasingly making district energy the cornerstone of their strategies to achieve 100 per cent renewable energy targets.

4.3. Urban Climate

Shaping the urban climate depends on the structure and the materials the city is made of. The urban climate differs from climates in landscapes, it is drier and warmer than in natural landscapes, and the heat loads of global warming add to these urban heat effects. The urban climate shows significant differences in the wind field where some places are more windy-protected, and some are more gusty. Many changes in urban structure also affect the urban climate, so it is important to understand the effects of design interventions on shaping the urban climate. Urban heat can be a problem, which may cause that over the day temperatures go very high and the release by night goes so slowly so that may still keep nearly the same temperatures. This capture of different urban areas heat may also be beneficial in creating windy corridors simulated by temperature differences through different areas. Temperature sensation depends on different factors, shortwave radiation from the sun and its reflection from urban surfaces. There is also longwave radiation which is the warmth that is emitted from objects in the city. When this heat emittance goes transmitted till night, it is called longwave radiation.

All these factors, like wind or shortwave sun radiation and longwave radiation, can be changed through local urban design interventions. More extensive scale interventions can also influence the air temperature and relative humidity. So, to provide shades close to the buildings, they have to be shaped and designed accordingly, for example, by arcade elements etc. For providing shades in public spaces, fixed or flexible elements such as movable curtains or elements can be used. Shades can also be created through vegetation that may consist of free-standing trees or grow trellises or pergolas. The advantage of vegetation is that it also tempers the air temperature through evapotranspiration. Vegetation, in this case, does ‘double duty for the prevention of urban heat; for instance, green walls and green roofs can lower the air temperatures and the temperature in buildings themselves.

4.3.1. Urban Heat Island Effect

Cities are especially vulnerable to higher temperatures due to the Urban Heat Island Effect, a phenomenon in a city that is generally warmer than its rural landscape. The urban heat island effect is most noticed during the evening and night. During this time, the air temperature over the metropolitan landscape shows considerable differences. On calm and clear nights, these air temperature differences between the urban and the rural area easily reach up to eight Celcius degrees. The urban heat island effect phenomenon is present in most urban areas, even in small villages. Various processes cause the formation of the urban heat island; the city consists of streets with buildings, these buildings trap the solar radiation that enters the street.

Other sources of heat include waste energy from electricity production, transportation, or heating and cooling of buildings. This energy heats up the buildings and streets, which can hardly escape during the night. In addition, human metabolisms are also counted as a source of heat in the city as well. All these things combined lead to higher air temperatures in the urban environment compared to the rural surroundings. Street geometry and availability of open water surfaces also influence the urban temperature. In more open streets and with low buildings, the heat stored in the pavements and buildings can escape more quickly, whereas in narrow streets and with high buildings, this heat is trapped and can’t escape. This aspect of open streets with low buildings and narrow streets with high buildings also varies for different seasons and latitudes.

Therefore, the influence of open water in the city reduces daytime temperatures when the air temperature reaches values higher than the water temperature. When the temperature of the air drops below the water temperature, the water has a warming effect during the night.

4.4. Building Integrated Modelling

Several different information models should be implemented for modelling a city, models of the buildings, parts of the buildings, etc. This structure level of information provides the basis of data that can be used for the overall sustainable analysis of buildings. The approach to BIM (Building Information Modeling), which is an open approach to building integrated modelling through different software, can create solutions for designing and implementing all data maps onto these designs, create a different alternative for the architectural solution to provide analysis for them and elaborate plans that will be used within the city. Database designers have important roles in linking different parameters to the buildings and implementing connectors to different providers. These basic connections are the elements that are analysed for obtaining good software tools in implementing BIM.

In the initial phases of the project design, BIM and database design enable a better understanding of the problems and the model; this leads to a good implementation and, therefore, to the basics of a good sustainable solution. To complete a systematic analysis on all key elements embedded in the database, the ISO standard is the basis that should be considered for the design of the database structures. In view of further changes, improvements, and integrations, these structures should be connected and easily operated within the model. This leaves no space for content to not be developed properly. This data design is also important for building future processes and management of the building. The data structure is key to help designers provide a good connection to library providers in the architectural model implementation, system architecture, and the software and the abstract data types exchanged with other materials and solutions. The selection of the tools and database structure architecture is crucial for implementing it and feeling it with data to help model the city. This modelling and highly implementation is a process that should also be followed within the city council level and, if possible, at the country or even further. The international standards level come to help for such point of implementation.

BIM sufficiency is established and provides all solutions already tested and developed through different standards. The following step is the integration at the national level, even the European one, whereby BIM reality is a very high commitment going forward in a powerful way. The most used software is Revit, developed by Autodesk, which has become the non-official standard for BIM implementation. Here, basic data such as CAD or even raster implementation can also be included in any other formats or information gathered through different point clouds. All these, together with the geographical information, are linked in BIM model, so the remaining parts of Revit non-spatial information, databases, cloud management of information and exchange format is the part that can help in matching the data of the materials to use and provide solutions on the analysis, sustainability analysis of the building and in the city context to be considered in 3D blocks for city analysis.

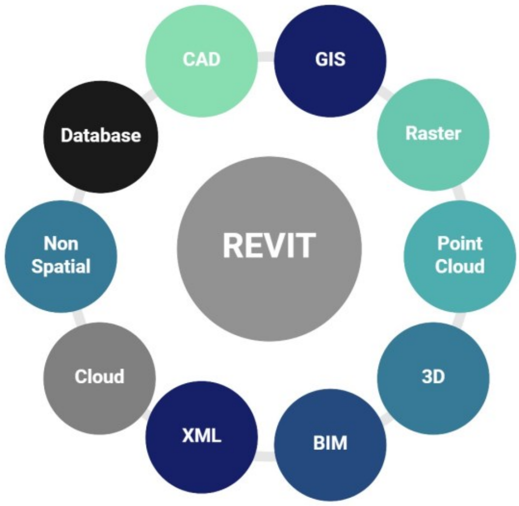

Figure 46 – Modelling a city format tools

These 3D models can include a surface implementation of the building, include a texture appearance infrastructure; all these possibilities are optional or desirable for performing the maintenance or different simulations subsequently. Different analysis can be performed, such as related to surfaces, orientation or even structural ones. Solutions for materials can be included for performing the automatization of different materials. Supplemental information can be incorporated, such as the detailed design of the building, the geometric properties obtaining the budget of the building or all data which is needed not only for mechanical analysis but also for sustainability implementation.

Crossing information implemented in the building models makes it easy to perform analysis or produce new data and deliver digital reports regarding buildings or on a more expanded scale. It is possible to extract data for maintenance and matching these quality standards. Digital reports and documents can be delivered or shared with contractors, subcontractors and other entities. On a bigger scale, these data can be beneficial for other service enablers such as service providers of electricity, gas, water or different assessors. This makes the overall picture of a life cycle cost analysis or holistic, sustainable life cycle assessment.

4.4.1. Modelling a City

Transformer Groups

- 3D – Extruder, 3Dforcer, MeshMerger,SurfaceSplitter etc.
- Surface Model – SurfaceModeller, TIN Generator,etc
- Texture and Appearance – Apparence Setter, Extractor, Styler, Joiner, Remover
- Infrastructure – Aggregator, Deagregator, Geometrycoercer

Surface – IFMECompositeSurface, IFME Multisurface, IFMEMesh

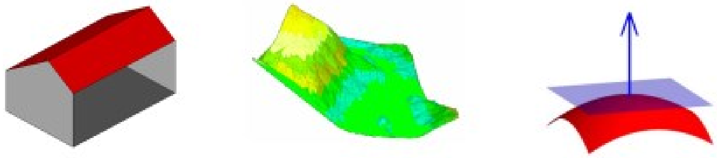

Figure 47 – Modelling a city format tools

- Solids – A solid is a volume (closed surface) in 3D space, defined by a collection of conducted surfaces. Solids can contain spatial voids.

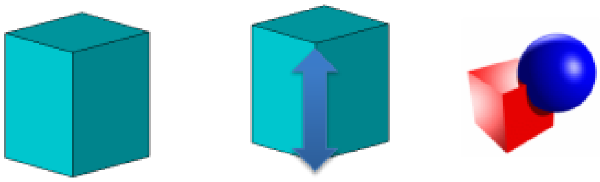

Figure 48 – Modelling a city format tools

- Geometry Properties

- Create 3D models from 2D data – workflow in FME (Feature Manipulation Engine)

  – Input in 2D or any 2.5D data

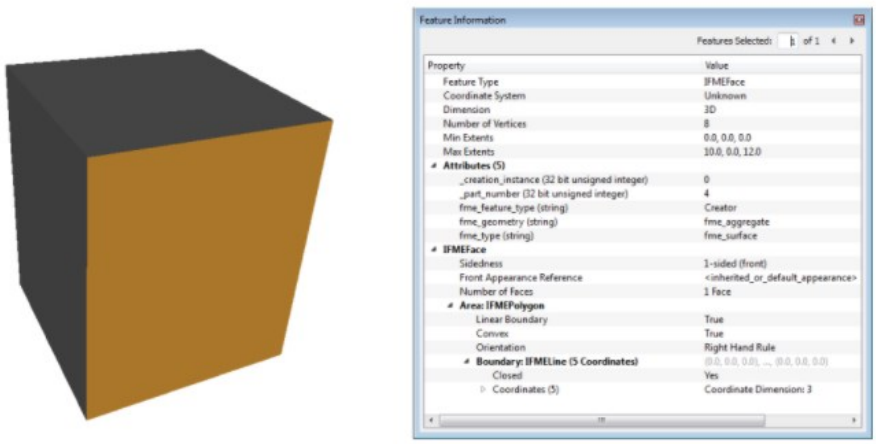

Figure 49 – Geometry properties

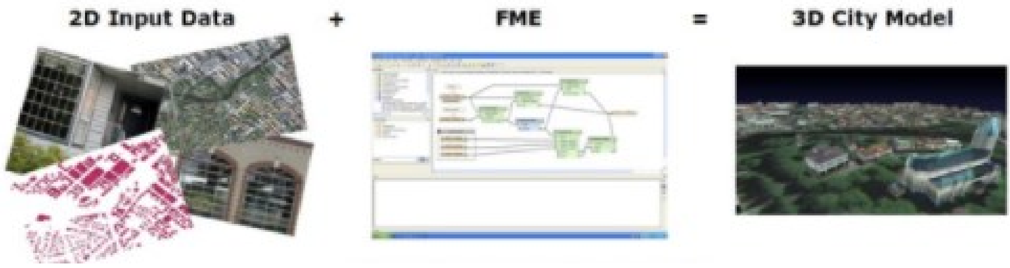

Figure 50 – 3D model from 2D data workflow

- Input Data

– Building footprints

– Land Use information (vegetation, water, traffic)

– CAD drawings

– Heights

– LiDar data

– Orthophotos

– Non spatial data (addresses, metadata)

- City GML is a data model and exchange format for virtual 3D city models
- Modeling of all relevant parts of a virtual city according to their semantics, geometry, topology and appearance
- GML 3 application schema (XML based)
- CityGML 1.0.0 is OGC Standard since 2008 -current version 2.0.0

- Coherence semantics and geometry
- External References
- Appearance (Textures)
- Application Domain Extensions (ADE)
- Generic city objects and attributes

Building Properties

- GML attributes – name, description, bounded by, etc.
- Core attributes – creationDate, terminationDate, relativeToTerrain, relativeToWater, external reference, generalizesTo
- Building attribuites – calss, function, usage, yearOfConstruction, yearOfDemolition, roofType, measureHight, storeyAboveGround, storeyBelowGround, stroeyHeightsAbove/BelowGround, address

Figure 51 – City of Berlin

Figure 52 – City of Karlsruhe

4.5. Life Cycle Assessment

Life cycle analysis considers different options and needs for buildings for the city through their entire lifespans. Lifespans of the city should be taken into account considering the available standards and databases, which help the design implement a solution for modelling these future smart, sustainable cities. According to the ISO standard, life-cycle analysis is a method for analyzing and determining the environmental impact along the product chain of technical systems. It includes different conversions of technical problems and manufacturing processes implementing through the life of the building, including the change of material chemistry, energy discharge through different materials and the assembly of all of them together.

According to ISO 14040, the formal definition is: “LCA is a technique for assessing the environmental aspects and potential impacts associated with a product, building, city or through compiling an inventory of relevant inputs and outputs”. So, balancing the inputs, outputs, evaluating process, and evaluation of the environmental impact enables one to compare different solutions regarding sustainability improvement. According to the product life-cycle designs, different elements that are considered in a city have to be taken into account from their raw state through manufacture, trade, transport, use, and final recycling or eventually waste management. All these elements are the basic chain for the LCA analysis.

Several different quantitative LCA techniques are applied in practice as a group of methods that use classification, characterization, normalization, and weighting.

The quantitative LCA method framework according to the standards 14040-43 are:

- Eco-points
- Eco-indicator
- EPS (Electric Power Steering) system
- MIPS (Material Input per Unit of Service) concept

The Eco-indicator and Eco-points methodology

The eco-indicator was first introduced in 1995 to provide engineers and designers with a simple method to estimate the environmental impact of proposed design solutions. It started with calculating the environmental loads from the product life cycle and weighing all of them to provide a final evaluation of the building and added them together to the city. It was thus the first place intended for internal use in companies when working with product development.

Implementation at the city level for architectural design has to consider not only the building level but also all the different elements through the life of the building, including the performance at sea level. For that part, there is an independent ISO16000 standard that provides solutions for different indicators.

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5. DIGITAL TWIN AT A CITY SCALE

5.1. Warrington Borough Use Case (ICL)

Digital Twin of the Northwest Project

This project aims to design and deliver a smarter energy system by Smarter Local Energy System from sources of energy and the potential storage energy at a coordinated level to understand synergies. These Smart Local Energy Systems aim to target the entire system cost and carbon reduction for the locality of the Warrington Borough and assess and understand the social impact and the potential benefit from these cost and carbon emission reduction.

The work undertaken for this project is to create a digital twin of the Warrington Borough to serve as a tool to guide the process towards decarbonatization. There are different definitions for digital twin, one of them is as a "realistic digital representation of assets, processes or systems in the built or natural environment".Center for Digital Built Britain. In this case, for the creation of a digital twin, first was needed the identification of an accurate and realistic representation of Warrington Borough incorporating the relevant data. The data have to be flexible, editable at the big levels and also at the lower level, i.e. that additional data can be incorporated as the project grows, but also be able to represent some several scenarios and also be able to evolve several developments itself.

The project is focused on an approximate area of 182km^2 located in Northwest England with a total population of 210 000 inhabitants with about 90.000 built structures in the Borough.

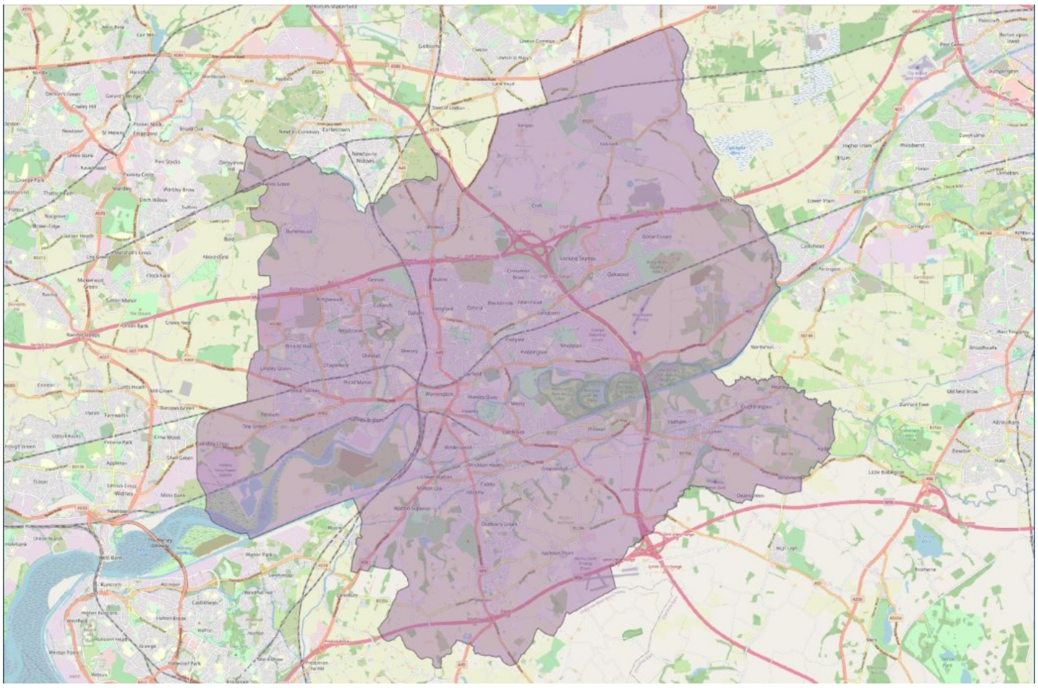

Figure 53 – Warrington Borough map

5.2. Challenges

Based on the first insight of the project goals and requirements, some of the identified challenges faced for the creation of such a tool are:

The scale of the project itself and the availability of the data, on the scale; the first challenge is to create the 3D model of 90.000 buildings, populate the data to each of these buildings, and assess energy consumption for each of them these objects. The last constraint is the time to create the entire model at the given time of the project. The main challenge regarding data availability is the sources where to gain the data, the quality, and how to mitigate the potential data gap.

Scale

- Create the model
- Populate data to each building
- Assess energy consumption
- Time constraint

Data Availability

- Sources
- Quality
- Data gap

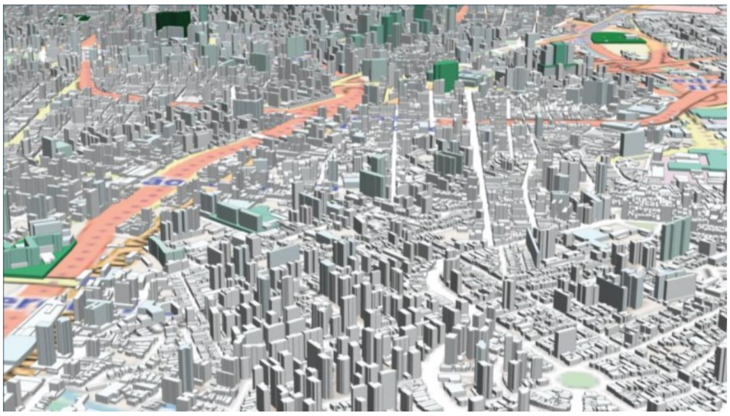

Figure 54 – 3D model Warrington borough

uprn	Address	PROPERTY	BUILT_FORM	GLAZED_TYPE	FLOOR_DESCRIPTION	WINDOWS_DESCRIF	WALLS_DESCRIPTION	ROOF_DESCRIPTION
100010275393	27, CUMBERLAND STREET, WA4 1HB	House	Mid-Terrace	double glazing installed during or after 2002	Solid, no insulation (assumed)	Fully double glazed	Solid brick, as built, no	Pitched, 75 mm loft insulation
100010275394	28, CUMBERLAND STREET, WA4 1HB	House	Mid-Terrace	double glazing installed during or after 2002	Solid, no insulation (assumed)	Fully double glazed	Solid brick, as built, no	Pitched, no insulation (assum
100010275396	30, CUMBERLAND STREET, WA4 1HB	House	Mid-Terrace	double glazing, unknown install date	Suspended, no insulation (assumed)	Fully double glazed	Cavity wall, as built, ins	Pitched, insulated (assumed)
100010275398	32, CUMBERLAND STREET, WA4 1HB	House	Mid-Terrace	double glazing, unknown install date	Solid, no insulation (assumed)	Fully double glazed	Solid brick, as built, no	Pitched, no insulation (assum
100010275399	33, CUMBERLAND STREET, WA4 1HB	House	Mid-Terrace	double glazing installed before 2002	Suspended, no insulation (assumed)	Fully double glazed	Solid brick, as built, no	Pitched, 100 mm loft insulatio
100010275401	35, CUMBERLAND STREET, WA4 1HB	House	Mid-Terrace	double glazing installed before 2002	Solid, no insulation (assumed)	Fully double glazed	Solid brick, as built, no	Pitched, 100 mm loft insulatio
100010275406	40, CUMBERLAND STREET, WA4 1HB	House	Mid-Terrace	double glazing, unknown install date	Solid, no insulation (assumed)	Fully double glazed	Solid brick, as built, no	Pitched, 100 mm loft insulatio
100010275407	41, CUMBERLAND STREET, WA4 1EZ	House	Mid-Terrace	double glazing installed before 2002	Solid, no insulation (assumed)	Fully double glazed	Cavity wall, as built, no	Pitched, 75 mm loft insulation
100010275410	44, CUMBERLAND STREET, WA4 1HB	House	Mid-Terrace	double glazing installed before 2002	Solid, no insulation (assumed)	Fully double glazed	Solid brick, as built, no	Pitched, 300 mm loft insulatio
100010275411	45, CUMBERLAND STREET, WA4 1EZ	House	Mid-Terrace	double glazing, unknown install date	Solid, no insulation (assumed)	Fully double glazed	Solid brick, as built, no	Pitched, 200 mm loft insulatio
100010275413	47, CUMBERLAND STREET, WA4 1EZ	House	End-Terrace	double glazing installed during or after 2002	Solid, no insulation (assumed)	Fully double glazed	Cavity wall, as built, no	Pitched, 150 mm loft insulatio
100010275414	48, CUMBERLAND STREET, WA4 1HB	House	End-Terrace	double glazing, unknown install date	Suspended, no insulation (assumed)	Fully double glazed	Solid brick, as built, no	Pitched, no insulation(assume
100010275415	49, CUMBERLAND STREET, WA4 1EZ	House	Mid-Terrace	double glazing installed during or after 2002	Solid, no insulation (assumed)	Fully double glazed	Cavity wall, as built, no	Pitched, 150 mm loft insulatio
100010275416	50, CUMBERLAND STREET, WA4 1HB	House	Mid-Terrace	double glazing, unknown install date	Solid, no insulation (assumed)	Mostly double glazir	Solid brick, as built, no	Pitched, 75 mm loft insulation
100010275417	51, CUMBERLAND STREET, WA4 1EZ	House	Mid-Terrace	double glazing, unknown install date	Solid, no insulation (assumed)	Fully double glazed	Cavity wall, as built, no	Pitched, 25 mm loft insulation
100010275421	54, CUMBERLAND STREET, WA4 1HB	House	End-Terrace	double glazing installed before 2002	Solid, no insulation (assumed)	Fully double glazed	Solid brick, as built, no	Pitched, no insulation
100010275425	57, CUMBERLAND STREET, WA4 1EZ	House	Mid-Terrace	double glazing installed before 2002	Solid, no insulation (assumed)	Fully double glazed	Solid brick, as built, no	Pitched, 50 mm loft insulation
100010275427	59, CUMBERLAND STREET, WA4 1EZ	House	Mid-Terrace	double glazing, unknown install date	Solid, no insulation (assumed)	Fully double glazed	Cavity wall, as built, no	Pitched, no insulation
100010275429	61, CUMBERLAND STREET, WA4 1EZ	House	Mid-Terrace	double glazing installed before 2002	Suspended, no insulation (assumed)	Fully double glazed	Cavity wall, as built, no	Pitched, no insulation
100010275431	63, CUMBERLAND STREET, WA4 1EZ	House	Mid-Terrace	double glazing, unknown install date	Suspended, no insulation (assumed)	Fully double glazed	Cavity wall, as built, no	Pitched, no insulation (assum
10008649717	10A, FLORENCE STREET, WA4 1DP	Flat	End-Terrace	double glazing, unknown install date	(another dwelling below)	Fully double glazed	Cavity wall, as built, no	Pitched, 75 mm loft insulation
100010264649	3, BEATRICE STREET, WA4 1DR	House	Semi-Detache	double glazing installed before 2002	Solid, no insulation (assumed)	Fully double glazed	Cavity wall, as built, par	Pitched, 200 mm loft insulatio
100010264652	9, BEATRICE STREET, WA4 1DR	House	End-Terrace	double glazing installed during or after 2002	Solid, no insulation (assumed)	Fully double glazed	Cavity wall, filled cavity	Pitched, 250 mm loft insulatio
100010275368	2, CUMBERLAND STREET, WA4 1HB	House	Mid-Terrace	double glazing installed before 2002	Suspended, no insulation (assumed)	Fully double glazed	Solid brick, as built, no	Pitched, no insulation (assum
100010275369	3, CUMBERLAND STREET, WA4 1HB	House	Mid-Terrace	double glazing installed before 2002	Solid, no insulation (assumed)	Fully double glazed	Solid brick, as built, no	Pitched, no insulation
100010275370	4, CUMBERLAND STREET, WA4 1HB	House	Mid-Terrace	double glazing, unknown install date	Solid, no insulation (assumed)	Fully double glazed	Solid brick, as built, no	Pitched, 250 mm loft insulatio
100010275371	5, CUMBERLAND STREET, WA4 1HB	House	Mid-Terrace	double glazing installed during or after 2002	Solid, no insulation (assumed)	Fully double glazed	Solid brick, as built, no	Pitched, 150 mm loft insulatio

Figure 55 – 3D model's data, Warrington Borough

5.3. ICL (Intelligent Communities Lifecycle) tools

For creating this digital twin, there are suits of several tools. The iCD (intelligent Cloud Data) is a Master planning & Urban design tool used to create models and populate the data into the models, and this is the main entry point for the digital twin. VE(Virtual Environment) is IES co-software, an energy simulation tool used to perform energy simulation on buildings. iVN (intelligent Virtual Network) allows to perform energy and carbon analysis at a larger scale, at a community scale, station scale, etc. iCIM, an online collaboration platform, is also the platform hosting the borough final digital twin.

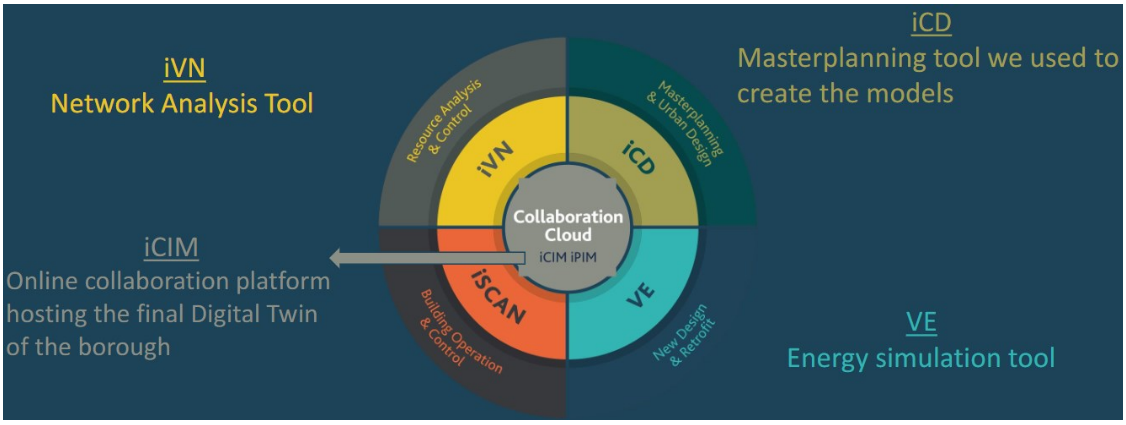

Figure 56 – The ICL tools

The first task for creating the model was splitting it into 29 models modelled individually in iCD and allowed to be gathered within a single platform. The model was divided into coherent urban areas and also limited the number of objects. Each model is synchronized within the same iCIM online platform, batching all these models and data altogether to create a digital twin.

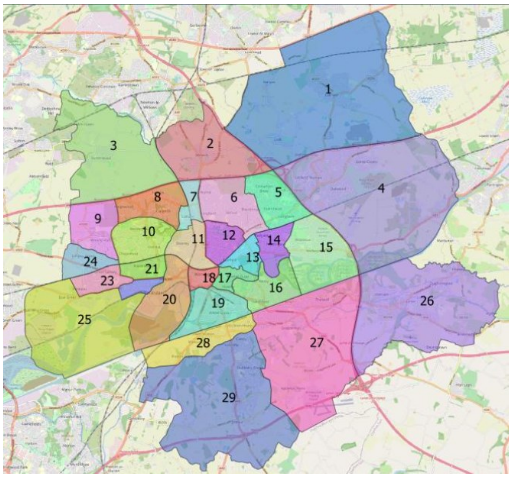

Figure 57 – Warrington split urban areas

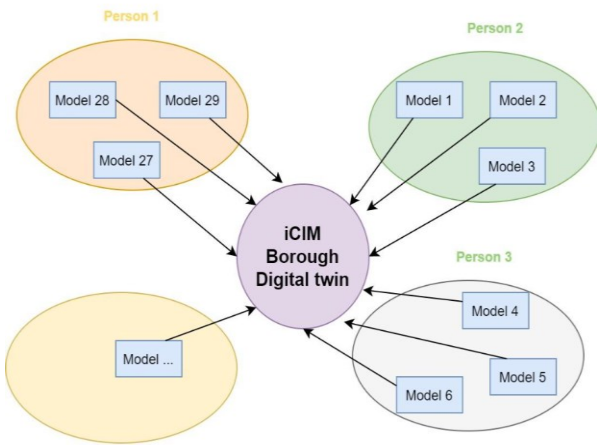

Figure 58 – Model split scheme

After creating the models, the first step is to identify the data and populate them with the relevant information. The first task is to populate geo-located geometries, property reference, and the building use provided by the borough council as a GIS file. The EPC(Energy Performance Certificate) database is considered and used as a CSV file for construction date and building characteristics. The electrical network data is provided by the electrical local network distribution operator with the geographical file as well, and all these data were imported in iCD. All these data were imported into two processes: GIS file import and the other CSV import.

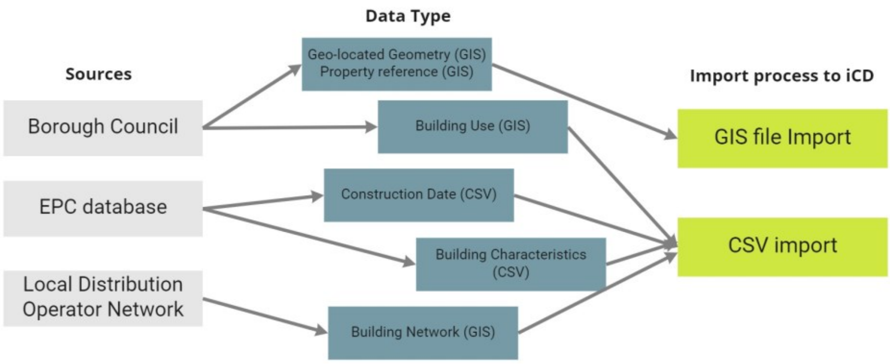

Figure 59 – Data population scheme

5.4. Geographical Data

The borough council has provided a set of the geographical data as GIS files, footprints of different buildings as polygon shapes as seen in Fig.60 and a model of GIS file providing property reference numbers, seen as the yellow spots in Fig.60. All these files and information are imported into the iCD environment to be converted automatically into buildings. The buildings are assigned with property reference numbers from the GIS data file, and they will serve to assign data information in the project. These 3D objects seen in Fig.61 are not only 3D models, but they also carry information called attributes such as the property reference number, for example.

Figure 60 – Borough building footprints

Figure 61 – Borough building 3D model

5.5. Building Use

The data provided by the council served for the basic use classification of the buildings in the iCD. The information was imported as CSV files and then was converted into the iCD from the previous use classification to the primary use into iCD as seen in Fig.62. Once the conversion work is done the data are imported and incorporated in the digital twin to ensure that each property is assigned the correct building use from the database. For doing such conversion, the properties' reference number served as a matching key.

Basic Land and Property Units Classification	iCD Primary use
Residential, Dwellings, Flat	Apartment
Residential, Dwellings, Flat	Apartment
Residential, Dwellings, Flat	Apartment
Commercial, Industrial, Factory / Manufacturing	Industrial
Residential, Dwellings, Terraced House	Single Family Terraced
Residential, Dwellings, Terraced House	Single Family Terraced
Residential, Dwellings, Terraced House	Single Family Terraced
Residential, Dwellings, Terraced House	Single Family Terraced
Residential, Dwellings, Terraced House	Single Family Terraced
Residential, Dwellings, Detached House	Single Family Detached
Object of Interest, Places of Worship	Church
Residential, Dwellings, Flat	Apartment

Figure 62 – Building use data conversion

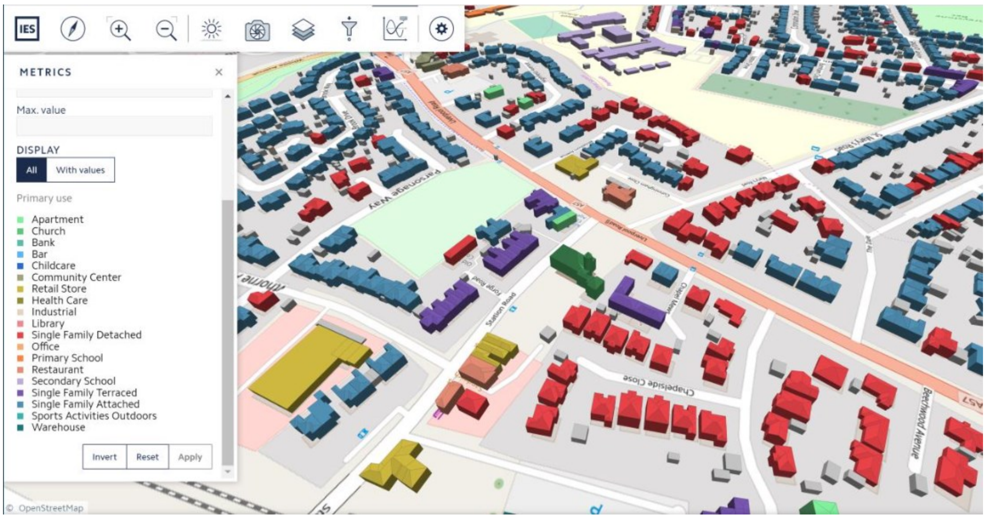

Figure 63 – Converted building use data in iCD environment

5.5.1. Network Data

The aim is assigning each building the reference of the substation connected to, for making possible energy assessment not only at building level but also the impact on larger scale such as substations and to understand if different scenarios can be generated in substations, like if additional electrical loads are needed etc. Of importance in this regard is the information imported from the local distribution network operator, such as geographical database including all the properties, the range of buildings they are covering by using the reference number, as a matching key for assigning different values to the substation reference number, the same also to the cable reference number.

Buildings Characteristics

Building characteristics were provided from the EPC (Energy Performance Certificate) database. The challenge was that the building imported information was lacking property reference numbers. This converted information was made possible through an algorithm that would assign the building addresses to property reference numbers. After this preparatory work, each property was assigned to a specific building envelope characteristic, assigned to each building with the specific reference number. Some of the existing building characteristics from the EPC matched to the new building envelope provided with property reference numbers are Construction date, Walls description, Roof description, Windows description and Floor description. The EPC database offers data on approx. 50.000 properties.

Figure 64 – Roof characteristics filtering

Figure 65 – Walls characteristics filtering

Figure 66 – Construction date characteristics filtering

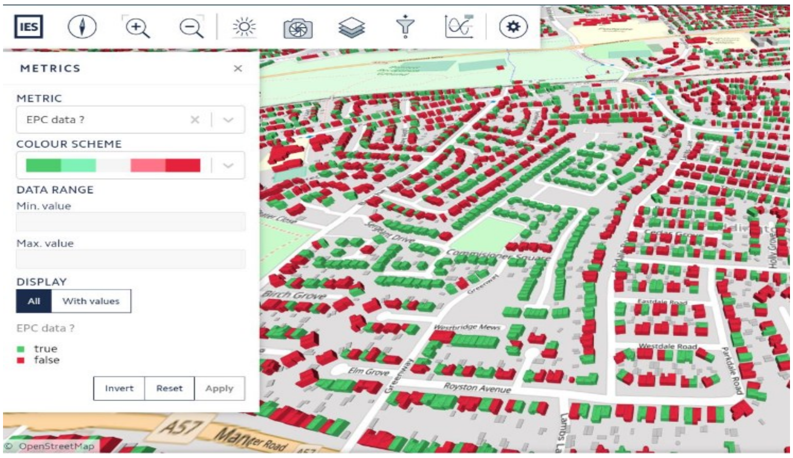

Figure 67 – Buildings possessing EPC database

5.5.2. Building Characteristics Data Gap

After checking the EPC for each property and its characteristics, an identification regarding form, and age band to look at their main trends regarding construction types, for each age band and built form make these main trends as default characteristics for similar buildings in the model. Once the EPC data was gathered, the same envelope data were applied to the buildings without EPC in the neighbourhood with the same conditions, built form and style.

5.5.3. Building and Identifying Archetypes

An investigation on the EPC database of over 50.000 properties and built form such as envelope characteristics, age band, main heating system, and total GFA (gross floor area) was performed to identify the building archetypes. For the residential buildings, four main built forms were established: Detached house, Semi-Detached House, Terraced house, Apartment

Building archetypes were identified for performing energy simulations in order to reduce the number of energy simulations required to populate the data in the digital twin. A variety of buildings considering the built criteria could be identified to the created archetypes. For each of these archetypal models were performed energy simulation into the energy simulation engine (VE, Decoupled apache) and these results were brought back to the digital twin environment and assigned to each building that was represented by that archetype. So after assigning each building to the archetypal building code, the data were easily and efficiently populated to the digital twin.

Differentiation criteria: Built form, Envelope characteristics (wall type), Construction date.

Same characteristics across the borough: Window type (double glazed), floors (uninsulated), main heating system (gas boiler with radiator)

Archetype	Detached 1	Detached 2	Semi-Detached 1	Semi-Detached 2	Semi-Detached 3	Terraced 1	Terraced 2	Terraced 3	Flats Pre-2003	Modern Flats
Floor Type	Solid Uninsulated U-Value = 0.7	Solid Uninsulated U-Value = 0.7	Solid Uninsulated U-Value = 0.7	Solid Uninsulated U-Value = 0.7	Solid Uninsulated U-Value = 0.7	Solid Uninsulated U-Value = 0.7	Solid Uninsulated U-Value = 0.7	Solid Uninsulated U-Value = 0.7	Solid Uninsulated U-Value = 0.7	Insulated Floor (2003 regs) = 0.25
Window Type	Double Glazed (pre 2003) U-value = 2.8	Double Glazed (pre 2003) U-value = 2.8	Double Glazed (pre 2003) U-value = 2.8	Double Glazed (pre 2003) U-value = 2.8	Double Glazed (pre 2003) U-value = 2.8	Double Glazed (pre 2003) U-value = 2.8	Double Glazed (pre 2003) U-value = 2.8	Double Glazed (pre 2003) U-value = 2.8	Double Glazed (pre 2003) U-value = 2.8	Double Glazed (post 2003) U-value = 2.0
Wall Type	Unfilled Cavity U-value = 1.5	Filled Cavity U-value = 0.5	Solid Brick U-value = 2.2	Unfilled Cavity U-value = 1.5	Filled Cavity U-value = 0.5	Solid Brick U-value = 2.2	Unfilled Cavity U-value = 1.5	Filled Cavity U-value = 0.5	Filled Cavity U-value = 0.5	Insulated Cavity Wall (2003 regs) U-value = 0.35
Roof Type	Pitched, Tiled U-value = 0.57	Pitched, Tiled U-value = 0.48	Pitched, Tiled U-value = 0.54	Pitched, Tiled U-value = 0.57	Pitched, Tiled U-value = 0.58	Pitched, Tiled U-value = 0.53	Pitched, Tiled U-value = 0.54	Pitched, Tiled U-value = 0.51	Pitched, Tiled Fully Insulated U-value = 0.2	Pitched, Tiled Fully Insulated U-value = 0.2

Figure 68 – Archetypes EPC database analysis

5.6. Archetype's Diversification

Another aspect of the rewire project was the model retrofit scenarios for Warrington. The archetype models were used for this analysis which provided two main benefits. 1) Each retrofit analysis was applied to a set of models diversifying the housing stock across the whole borough. 2) The analysis will produce a more diverse set of energy profiles that can be assigned to the digital twin for houses with higher thermal performances than the default archetypes.

5.7. Energy Simulations

A number of energy simulations were performed in the VE (Virtual Environment) through the decoupled apache engine, considering the conservation measurements taken from the standards. The advantage was that many large simulations were performed, reducing time and the number of runs. All the building parameters vary on the envelope characteristics of the wall, roof, key setpoints, etc. These are specified before the simulations and are run through python code with all combinations of simulations. The results are gained simultaneously, and all at once, in terms of total energy, total gas etc. Besides the development of improvements of the ECMs, Decouple apache engine can also run variations of simulations on human factors, property-specific parameter variations like heating, setpoints, infiltration, lighting power density, and building orientation. So, for every basic archetype and every ECMs scenario, it was made possible to improve series of values to get the full potential of energy savings.

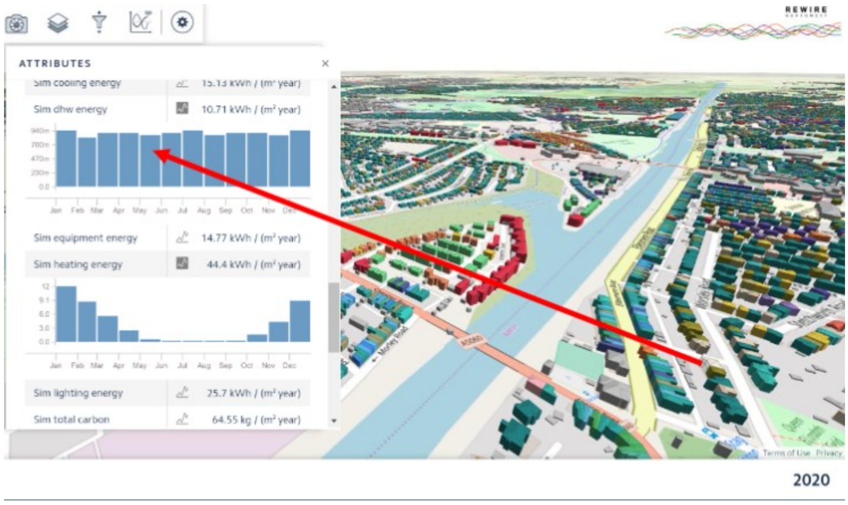

Figure 69 – Energy simulation results & time series based on archetype

Thanks to the archetype models created, time-series profiles are generated that can be assigned to each building in the digital twin. After the analysis, we have profiles associated with the improved scenario for each of these buildings. So, if the building envelope improves according to the regulation standards, we can use these profiles in future network analysis. Any area in the digital twin can be picked, for example, a specific set of buildings or a few streets in the neighbourhood or could be all the buildings connected to one substation as highlighted in Fig.70. The selected buildings and the associated profiles can be imported from the iCD model to the iVN, a network analysis tool.

Figure 70 – Series profiles for network modelling at a community scale

Once the buildings are in the iVN we can perform detailed network analysis for this area. So, we can model the current situation for the current profiles and see the total electricity and heating demand on the network for this area. Also, potential future scenarios can be modelled, such as the addition of installations like PVs on each home or types of energy storages, or the impact of the electric vehicles on electricity demand. By modelling these installations, we can see if it is possible to generate enough electricity from renewable energy sources to emit zero-energy buildings in this area.

The other aim is to decarbonize the Warrington borough. To do this, it is required to reduce the heating demand, to reduce the gas consumption, using the improved building envelope profiles generated from retrofit analysis done previously. By applying these profiles in iVN, we can compare the current base assigned scenario in the area with the ones retrofit measures are applied and see the impact of applying retrofit at scale. Other methods towards decarbonising are switching the heating systems to electrical systems or using heat pumps. These modelled situations can be compared with the total demands towards the new demands of the area in the iVN. By switching to electric heating demand, the network will increase, so this scenario could have to upgrade the network cables to cope with this demand. So, the models can also show how this can be avoided by reducing heat demand through means such as storage or demands and response.

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6. CONCLUSIONS

This work provides a comprehensive view of how smart cities function. The major problems and challenges that smart city development and implementation faces today are delineated, especially regarding digitalization in real-world. The mechanism which drives digitalization trends for the cities, and its implication has been outlined. In terms of strategy, digitalization should be comprehensive, involving and encouraging participation of public from all sectors and levels of urban life. Progress and application of digitalization intend to improve efficiency and sustainability regarding business opportunities and the well-being of the people.

It is of great importance the determination of the basic strategies whether they should have a horizontal integration, which sometimes leads to several coordination issues and challenges for sharing and top-down administration. Since some smart city projects seem to have come up from a bottom-up strategy, it is still unclear how the various elements will be joined together to provide a better holistic and efficient comprehensive management of the city at this stage.

A review on the energy systems structure shows how they were developed from vertical legacy systems to smart systems of distribution which appear nowadays in cities; actors involved in such transition, the challenges, key issues for policymakers and managers and what are some of the consequences for smart urban energy systems, especially in terms of new services and data layers.

The promising innovative ideas have a great potential for increasing resource efficiency improving at the same time inhabitants' quality of life, particularly when it comes to connecting energy services with other urban grids, like mobility.

Understanding the characteristics which make the socio-technical systems difficult to manage, as well as challenges in transitional services and infrastructure layers are essential steps to be taken to reduce the risks of a system transition; they are important issues to be dealt with by policymakers and managers in planning and managing the transition and drafting the strategies.

The notion of urban metabolism has proved to be useful in organising the huge amount of complex data incorporated in city systems in preparation for including additional dynamic data sources into static City Information Modeling.

The establishment of sensory systems are very important for gathering urban data flows to be subsequently shared in an accessible data platform. The collection of such data will positively impact increasing transparency, reducing the risk, increasing quality and efficiency, and addressing the issues by stakeholders. Planners and managers consider CIM as an opportunity to help them design the city and address the issues of the city areas so that the city functions appropriately.

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LIST OF ACRONYMS AND ABBREVIATIONS

API	Application Programming Interface
ArcGIS	GIS Mapping Software, Location Intelligence & Spatial
BIM	(Building Information Modelling
BREEAM	Building Research Establishment Environmental Assessment Method
CASBEE	Comprehensive Assessment System for Built Environment Efficiency
CGIS	Canada Geographic Information System
CIM	City Information Modelling
DEA	Data Envelopment Analysis
DOA,	Direction of Arrival
EM	Electromagnetic Radiation
EPC	Energy Performance Certificate
EPS	Electric Power Steering
ESRI	GIS Mapping Software, Location Intelligence & Spatial
GFA	Gross Floor Area
GHG	Green House Gas emissions
GPS	Global Positioning System
GRASS	GRASS GIS is a free Geographic Information System (GIS) software
iCD	Intelligent Cloud Data
iCIM,	Online Collaboration Platform
ICT	Information and Communications Technology
KML	Keyhole Markup Language
LEED	Leadership in Energy and Environmental Design
MIPS	Material Input per Unit of Service
MVC	Model View Controller
PDOA	Phase Difference of Arrival
POSSA	Pattern-Oriented Software Architecture
QGIS	QGIS is a free open-source mapping software, location & spatial
RFID	Radio-frequency identification
RSS,	Received Signal Strength
RSSI,	Receive Signal Strength Indication
SBTool	Sustainable Building Tool
SQS	Simple Queue Service
SSID,	Service Set Identifier
TDOA,	Time Difference of Arrival
TOF	Time of Flight
UI	User Interface
VE	Virtual Environment
VGI	Volunteered Geographic Information
WiMax	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network

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