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# MASTER THESIS

## Development of a synthesis concept for the Smart City Maun Science Park

Integration of (digitally) re-programmable space by using the Internet of Things

**Development of a synthesis concept for the**
**Smart City Maun Science Park**

Integration of (digitally) re-programmable space
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MASTER THESIS

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## Abstract

Cities around the world are facing an increasing number of global and local challenges, such as climate change and scarcity of raw materials. At the same time trends like digitalization, globalization and networking gain in importance. For this reason, cities have started implementing smart solutions within the urban structure in order to evolve towards a Smart City. In Botswana, the Maun Science Park is intended to provide a best practice approach for a Botswanan Smart City. Since Smart City concepts have to be specifically tailored to local conditions, the first main goal of this thesis is to develop a synthesis concept for the Maun Science Park. A key problem in cities is the utilization of space, which is further intensified by increasing urbanization and population growth. Therefore, the second main goal is to develop approaches of (digitally) re-programmable space to use available areas intelligently and optimized.

Within the thesis, human-centered design has been applied as structure-giving methodology. By clarifying relevant Smart City contents, considering reference examples as well as identifying local challenges and requirements, an appropriate concept has been developed with human-focus. Furthermore, the methodologies of literature research and expert interviews have been used as input in the individual human-centered design phases. In combination with an innovation funnel, the methodology human-centered design forms the structure of the thesis.

In total, ten main solution areas and 37 sub-segments have been identified for the synthesis concept of Maun Science Park. Additionally, a concept for Smart Buildings has been developed as a part of the synthesis concept and as an essential infrastructure component of the Maun Science Park (three main segments, 16 sub-segments). Based on expert input, a prioritization has been determined by evaluating the impact and economic affordability of the individual sub-areas. Moreover, individual key areas have been highlighted by identifying direct interactions between sub-segments and on the basis of expert input – these are particularly related to the segments Smart Data and Smart People. Besides the synthesis concept, approaches of (digitally) re-programmable space have been created. Thereby, ten approaches refer to the conversion, reuse or expansion abilities of space within daily, weekly or life cycle. In addition, the conventional (digitally) re-programmable space idea has been extended by two new considerations – “multi-purpose use of built-up space” and “concept programming in the planning phase”. Finally, within an overall consideration – synthesis concept combined with approaches of (digitally) re-programmable space – the added value of the developed contents has been outlined, positive and negative aspects have been identified within a SWOT analysis and the business model of the Maun Science Park approach has been verified in a Business Model Canvas.

Through explicit elaboration, classification and prioritization of solution areas, the developed concept can serve as a basis for further project steps. Based on the defined requirements of the sub-segments, solutions can be developed with regard to the entire Smart City context.

## Table of contents

## List of Figures



## List of Tables

## List of Abbreviations

| | |
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| 4IR | Fourth Industrial Revolution |
| AI | Artificial Intelligence |
| BIM | Building Information Modeling |
| CPI | Corruption Perceptions Index |
| GDP | Gross Domestic Product |
| ICT | Information and Communication Technologies |
| IoT | Internet of Things |
| LPI | Logistics Performance Index |
| MSP | Maun Science Park |
| PV | Photovoltaic |
| RFID | Radio Frequency Identification |
| VR | Virtual Reality |

# 1 Introduction

The introduction describes the subject of the present paper and leads to the topic. Furthermore, problems as well as objectives are explained and the methodology is described.

## 1.1 Introduction to the topic

Life in cities combines a variety of positive and negative aspects at the same time. On the one hand, cities are economic centers, offering an attractive living environment and serving as drivers for a successful future. On the other hand, global trends such as urbanization (urbanization rate 2018: 55%, 2050: 66%) and population growth (worldwide population 2019: 7.7 billion, 2050: 9.7 billion) are leading to increasing infrastructure congestion, resulting in air pollution, higher crime rates and economic losses.[1] At the same time the world is changing. Increasing networking brings comprehensive advantages in various areas. However, this trend is only slowly being implemented in today's buildings and cities. One reason for this is the hesitantly adoption and implementation of megatrends in today's economy and society, such as digitization, globalization and connectivity, in the construction industry.[2] But the great benefit lies specifically in networking of entire cities. The more data is generated, the more significant the decisions for the operation of the cities and the future. Resource consumption such as energy and water is optimized, overall urban mobility is improved and daily life is simplified, leading to a better quality of life in cities. Economic advantages can be achieved by using collective intelligence, especially by adopting a leading role in the development of smart concepts and approaches.[3] Thereby entering these trends in this area offers an enormous potential, as the Smart Building market is expected to grow by 32% annually.[4] Therefore, cities all over the world are starting to work with new ways of thinking on solutions and concepts to prepare the urban environment for the future, to manage local challenges and to gain a competitive advantage. They transform the urban structure with technology into a Smart City.

## 1.2 Problem definition and objectives

Botswana has initiated the nationwide Fourth Industrial Revolution (4IR)/Digital Transformation Strategy in order to transform to a knowledge-based society. The Maun Science Park (MSP) is intended to contribute to this strategy by serving as a reference example for a Botswana specific Smart City. As already mentioned, Smart City concepts are currently in the process of being developed all over the world. However, these approaches are based on local requirements, which are often not comparable to Botswanan ones. Besides global problems such as increasing urbanization, infrastructure congestion and climate change, cities and people in

[1] cf. Gassmann et al. 2018, p. 1; United Nations Department of Economic and Social Affairs 2019a, pp. XIX, 1
[2] cf. Zukunftsinstitut 2018
[3] cf. Deloitte 2020
[4] cf. cf. Apanaviviene et al. 2020, p. 3

Botswana have to struggle with food and water shortages, problems within the energy supply, lack of waste management and conflicts with animals. As a result, an overall concept specific to Botswana is required to meet local challenges and requirements of the inhabitants. Therefore, the first main goal of the thesis is to establish a synthesis concept for MSP as well as for the Smart Buildings, which combines the original Smart City idea with local requirements. For this purpose, solution areas for MSP and Smart Buildings are to be defined in order to combine these to an overall concept appropriate to MSP and its environment. Thereby, the objective is not to provide specific solutions in the individual areas, but to structure a holistic concept into different solution areas and to define requirements for them. Furthermore, this thesis should also identify the areas with the best affordability-impact ratio in order to derive prioritization.

In addition, cities struggle with space problems in various infrastructure areas, because of increasing population and urbanization. Moreover, on the one hand, for people, firms and cities, buildings are a high cost factor while they are frequently confronted with lack of space – in case of cities in several infrastructure areas. On the other hand, within the urban structure there are often many unused or underutilized spaces, as these not meet today's requirements or are intended for use cases that are no longer required. Besides these problems Botswana cities are facing fragmentation and informal neighborhoods. Therefore, the need of intelligent space planning, utilization and reuse is rising. This trend was ranked at first among the Top 10 urban innovations of the WORLD ECONOMIC FORUM in 2015 – named (digitally) re-programmable space. Therefore, the second main objective is to create approaches of (digitally) re-programmable space for various infrastructure areas based on the local and project requirements and with the help of Internet of Things (IoT).[5] Afterwards, the developed concepts as a whole – synthesis concept combine with approaches of (digitally) re-programmable space – should be critically examined for practicability. For this purpose, the analyses Business Model Canvas and SWOT are applied.

## 1.3 Approach and methodology

Human-centered design is used as a structure-giving methodology within the present thesis. This methodology was chosen because the process is focused on humans and gives priority to them. That means a development based on people's needs and local challenges.[6] HOLLENBACH divides the process into three phases – inspiration, ideation and implementation.[7] The exact contents of the individual phases and the methodology are outlined in Figure 1 as well as the allocation of the phases to the specific chapters and their contents. A central component of the ideation phase is an iterative procedure. Therefore, requirements are defined on the

[5] cf. World Economic Forum 2015, p. 4
[6] cf. Burmester 2016
[7] cf. Hollenbach 2020

basis of the inspiration phase, a concept is developed along them and with a focus on people and finally the developed concept is compared with the defined requirements.[8] If these requirements are only partially met, the iteration process is repeated. It should be noted that the comparison between the developed concept and the defined requirements and challenges took place, but the content of the individual iteration phases is not shown in the thesis.

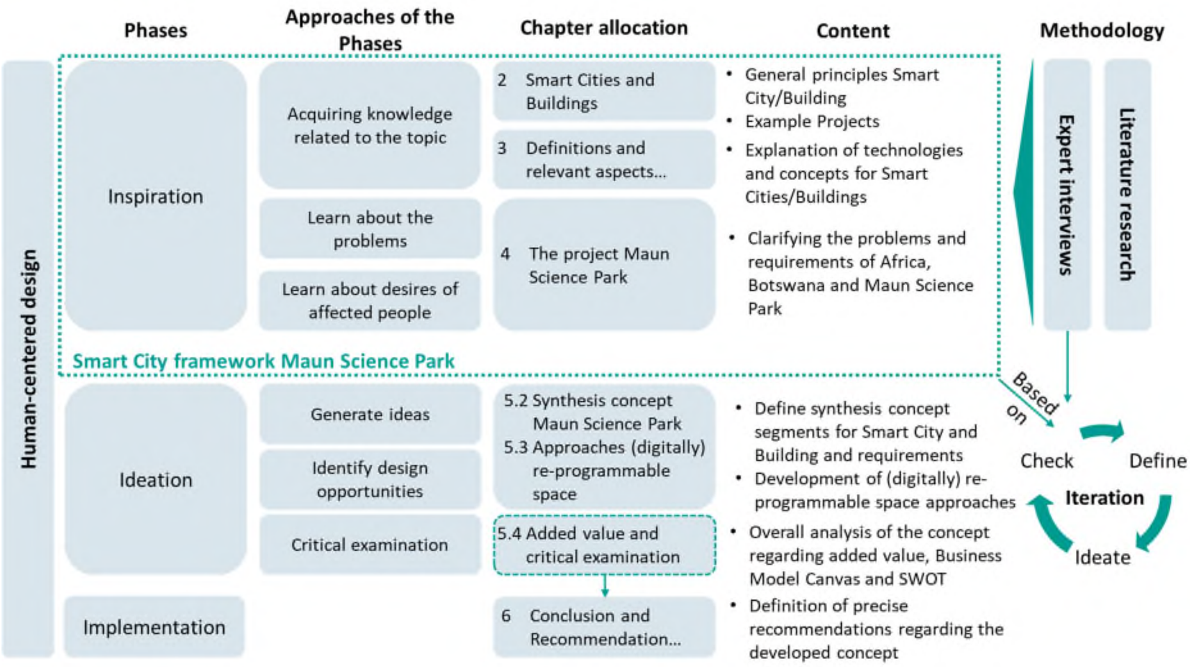


*Figure 1: Methodology framework*[9]

As shown in Figure 1, two further methodologies – literature research and expert interviews – are embedded within the methodology of human-centered design. These serve as input for the Smart City and Building approaches as well as for local requirements and challenges, thus providing the basis for the development of the concepts in line with human-centered design. Within the comprehensive literature research, books, research papers and internet sources were used. For the interviews a semi-structured approach was applied. This means that in advance of the interview a guideline with open questions, which allow flexible answers, was created. During the meeting, the interviewer responded intuitive and flexible to answers. Therefore, contents have been specified and, if applicable, new ideas have been gained through the interview. As a result, by applying these two methods, the basics have been established within the inspiration phase. In addition, expert interviews were used in the iterations process within the ideation phase as well. Thereby, the interviews were structured only by the contents of the developed concepts in order to enable an open discussion about the created approaches.

[8] cf. Burmester 2016
[9] own illustration based on Hollenbach 2020

Furthermore, the creation of a Smart City framework as a basis for the development of a comprehensive concept was integrated into the human-centered design approach. Based on Chapter 2, a general Smart City framework was created. This is further detailed in Chapter 3 by specifying key features of a Smart City. In Chapter 4 the framework is adapted to Botswanan and MSP specific boundary conditions. Afterwards, the framework, generated in the inspiration phase within Chapter 2 to 4, is used as a basis for the second human-centered design phase – ideation phase – and thus for the development of the synthesis concept and the elaboration of (digitally) re-programmable space approaches in Chapter 5.

## 1.4 Structure of the thesis

The following work is organized along an information funnel based on the methodology already explained (see Figure 1). This means a structuring from completely general information – not related to the MSP project – towards a specific component, the integration of (digitally) re-programmable space into the project. Figure 2 shows this structure graphically. The structure of the thesis and the contents of the individual chapters are explained in more detail below.

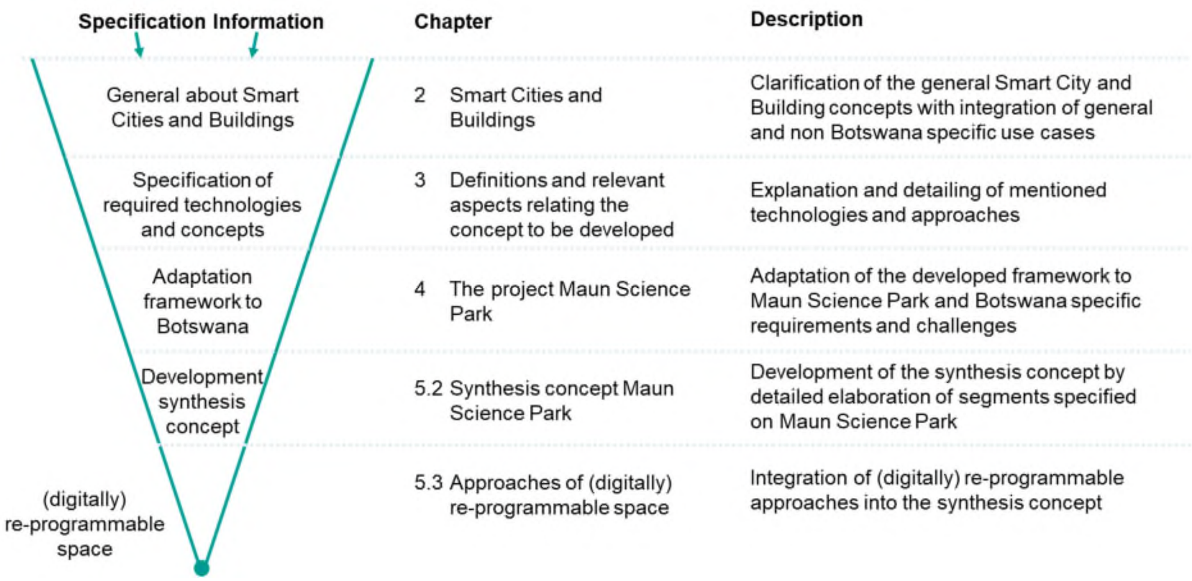


*Figure 2: Thesis organization based on information funnel*

The present thesis is divided into six chapters. The introduction serves to familiarize the reader with the topic, to clarify the aim of the work, to explain the chosen methodology and to show the structure.

Based on a comprehensive literature research, Chapter 2 explains the general approach of Smart Cities and Buildings. This includes the definition of the two terms, the drivers for change, the fields of actions and development stages of a Smart City as well as the basic interaction between buildings and the city. In addition, general use cases and project examples are presented for both, Smart Cities and Smart Buildings, to illustrate the diversity of the approaches. This fundamental theoretical knowledge is needed to understand the topic and to develop a synthesis concept.

Chapter 3 specifies the technologies and concepts that form the basis of a Smart City and the present study. These are in particular the approach of (digitally) re-programmable space, Internet of Things (IoT) and digital twin. In addition, approaches for handling data are explained as well as possibilities for the interaction between people and technology are outlined. As a result of the chapter, contents of a Smart City are further specified.

In order to develop a concept specifically designed for the MSP, specific requirements of Botswana and MSP have to be considered. For this purpose, Chapter 4 describes the boundary conditions and challenges regarding social, ecological and economic aspects from Botswana. Furthermore, the vision, goals and core elements of the MSP are described. Thus, Chapter 4 enables the adaptation of the framework developed in Chapters 2 and 3 to a MSP framework and serves as a basis for the specification of a Smart City concept to the local boundary conditions – information within the information funnel is further specified.

In Chapter 5 the synthesis concept as well as approaches for (digitally) re-programmable space are developed. First of all, the procedure is explained. Afterwards, the synthesis concept is created on the basis of the Smart City framework MSP in form of definition of segments and description of requirements for the segments of Smart City and Buildings. This also includes prioritization by evaluating impact and economic affordability of the various areas, highlighting of important issues and identification of direct interfaces between the segments. Based on the synthesis concept and the boundary conditions of Chapter 4, approaches of (digitally) re-programmable space with the help of IoT specifically for the MSP are created. Finally, the overall added value is outlined as well as the practicability is shown in form of a Business Model Canvas and a SWOT analysis. Within Chapter 5, the contents of the information funnel are specifically directed to the approach of (digitally) re-programmable space. Finally, Chapter 6 concludes the study and presents recommendations for action.

It should be noted that the information is oriented along an information funnel within the thesis. Thereby the human-centered design indirectly determines the contents of the chapters. Chapters 2 to 4 are for the inspiration phase. Chapter 5 is for the ideation phase. Finally, Chapter 6 serves as the implementation phase, based on the analyses developed in Chapter 5. Consequently, a combination between increasingly specified information and human-centered design is established.

# 2 Smart Cities and Buildings

Chapter 2 deals with the terms Smart Building and Smart City as well as shows how the two concepts interact and can be connected. Subsequently, a Smart City framework will be developed for this elaboration based on a comprehensive literature research. In the later course of the thesis this framework is adjusted to specific requirements of Botswana respectively MSP.

## 2.1 Smart Cities

Smart City is a comprehensive concept with different goals. In this chapter the term is defined, components and drivers are described and the goals and benefits are shown. Afterwards different use cases are mentioned to show the variety of possibilities and concepts that can be used in a Smart City.

### 2.1.1 Definition and goals

There is no uniform definition of a Smart City concept in the literature. For this thesis the definition with included goals of UNECE is adopted: "A smart sustainable city is an innovative city that uses Information and Communication Technologies (ICT) and other means to improve quality of life, efficiency of urban operation and services, and competitiveness, while ensuring that it meets the needs of present and future generations with respect to economic, social, environmental as well as cultural aspects”.[10] Core technologies for the implementation of this concept are especially IoT, robotics, Virtual Reality (VR), Augmented Reality, Artificial Intelligence (AI), Big Data technology, 5G technology or Global Positioning Systems.[11] This is intended to create a completely digitally networked city, which can thus be visualized, controlled and optimized in terms of its entire operation with mobility, administration, energy, infrastructure, etc. In the transformation process to a Smart City, it is essential to develop in line with the relevant requirements and to integrate and interconnect the various sub-areas.[12] As a result, the benefits in terms of ecology, growth capacity and urban life are broad, as specifically described in Chapter 2.1.4 with regard to the various sub-parts.

### 2.1.2 Drivers

Various factors complicated life in cities and require the transformation to a Smart City. In the literature a variety of drivers are identified, which are summarized in this study on the core issues demographic change, infrastructure congestion, ecological aspects, decision making process and economic challenges.

[10] United Nations Economic Commission for Europe 2017
[11] cf. Fourtané 2018
[12] cf. Gassmann et al. 2018, p. 17

**Demographic change**

Demographic change is affecting many countries nowadays. The main reasons for this are falling birth rates and the continuing rise in life expectancy, leading to an increase in the number of older people. However, cities and digital applications are often designed for the young population. As a result, in the future concepts and structures in cities must be developed to ensure mobility and medical care for elderly.[13]

**Infrastructure congestion**

The infrastructure of cities is under increasing strain due to population growth. The main reason in particular is the interaction between urbanization and general population growth. In 2018, the urbanization rate was 55%, by 2050 it is expected to rise to 66%.[14] At the same time, the world population is expected to increase from 7.7 billion (2019) to 9.7 billion (2050), resulting in 2.2 billion more people living in cities by 2050.[15] This extreme growth cannot be handled by the existing infrastructure. The available space will no longer be sufficient for people, which will lead to an increase in housing shortages. Due to increasing traffic volume, mobility will collapse and waiting times will increase dramatically, which leads to a significant welfare loss. The water and energy supply of cities can no longer be absorbed by the existing network. In addition, a higher number of people will lead to higher emissions and waste volume, which in turn will have a negative impact on the health of the inhabitants.[16] Such scenarios cause residents to become dissatisfied and increase the gap between social classes, resulting in higher crime rates. Taking all this into account, the rapid population growth in cities leads to a fragile infrastructure, which needs intelligent concepts to compensate.

**Ecological aspects**

Climate change, scarcity of resources as well as the already mentioned increasing emissions in cities due to population growth must be considered as ecological aspects in urban development. Cities must focus on a system that is regenerative. This requires a balanced and optimized use of renewable resources and the application of low-emission mobility concepts. In addition, ideas must be created to reduce the amount of space required and therefore to prevent sealing areas as well as to design new green spaces. A holistic concept is needed that communicates with other cities in order to counteract the worldwide environmental challenges.[17]

[13] cf. Gassmann et al. 2018, p. 9
[14] cf. United Nations Department of Economic and Social Affairs 2019a, p. XIX
[15] cf. United Nations Department of Economic and Social Affairs 2019a, p. 1
[16] cf. Gassmann et al. 2018, pp. 10-11
[17] cf. Lauzi 2019, p. 13

**Economic challenges**

Cities must remain competitive in the future in order to remain interesting for talents and firms. This can only be ensured by creating an attractive infrastructure, environment and administration that attracts globally competitive companies. If this cannot be guaranteed, it will lead to a loss of tax revenue due to migration and declining purchasing power, which will have a negative impact on urban development and competitiveness in international terms, ending in a downward spiral.[18] Therefore, in the future new concepts and systems shall be used by cities to differentiate themselves from other cities or countries.

**Decision making process**

In cities, the ongoing social, environmental and economic challenges are not only affected by government but also by firms and individuals. As these are the main knowledge carriers in an economy, they are willing and required to be involved in future decision-making processes, which will lead to greater transparency and confidence.[19] This requires a high degree of flexibility in order to be able to develop constantly and adapt to new conditions and trends in the environment as well as a stakeholder accessible collaboration network.[20] These types of concepts can be created by technologies like IoT, which provide all relevant information and enable it to be connected to each other. Through these comprehensive data as well as through the proactive participation of all people and organizations a collective intelligence is intended, which allows to involve desired co-creation processes. As a result, collective intelligence enables the creation of a better decision-making process for cities, organizations and individuals.[21]

### 2.1.3 Development stages

Cities, in particular existing ones, can often not be transformed directly into a full-scale Smart City, development stages must be defined and passed through. The literature uses different types of development stages of Smart Cities (e.g. Cohen 2015; Deloitte 2015, p. 36-39). In this thesis the approach of COHEN is used, which divides the development of a Smart City into the following three generations (some of the examples mentioned are discussed in Chapter 2.1.5):

- Smart Cities 1.0: Technology driven (e.g. Songdo City)
- Smart Cities 2.0: Technology enabled (e.g. Barcelona)
- Smart Cities 3.0: Citizen co-creation (e.g. some projects in Vancouver or Vienna)[22]

Smart Cities 1.0 are characterized by adopting new technologies in the city's infrastructure, but without taking into account the overall context and technological impact, particularly in the

[18] cf. Lauzi 2019, pp. 12-13
[19] cf. Lauzi 2019, p. 13; Deloitte 2018a, p. 6
[20] cf. Gassmann et al. 2018, p. 15; Deloitte 2018a, p. 6
[21] cf. Deloitte 2018a, p. 6
[22] cf. Cohen 2015

context of the residents' well-being. This stage is usually driven and influenced by private high-tech firms. In the Smart Cities 2.0 phase, the city administration takes the leading role in terms of the application of the technology within the Smart City concept. The focus is the development of a network of technologies that will improve the quality of life and service within the city. In Smart Cities 3.0, urban development activities will be based on co-creation approaches. This enables the residents to collaborate with their knowledge and benefit from technologies and digital platforms for a transformation of the city. This will result in new concepts, projects and businesses, improving the quality of the entire environment.[23]

Some cities are going through all the individual phases towards Smart City 3.0. Other cities will skip individual phases or directly progress to Smart City 3.0. Still others will develop into a generation and remain at that stage. A combination of projects in cities at different stages of development is possible as well. According to COHEN, a mixture of level 2.0 and 3.0 is the best choice for a successful future, since the city administration must continue promoting economic growth and because often it is difficult to implement solutions that enable the population to make decisions on their own.[24]

### 2.1.4 Segments of a Smart City

In the literature, Smart Cities are divided into different components, but there exists no uniform classification in this context. For this work, the structure of GASSMANN ET AL. (others with the same classification: EJAZ & ANPALAGEN or LOMBARDI ET. AL) is used, which divides Smart Cities into smart environment, smart living, smart economy, smart mobility, smart government and smart people.[25]

#### Smart environment

The smart environment component is focused on minimizing the ecological footprint. The focus is on intelligent concepts at micro and macro level that will not have a negative impact on the two areas of mobility and living. On the one hand, smart environment involves reducing pollution and creating a sustainable urban structure. This can be achieved by maintaining green spaces and initiatives for the creation of new green spaces that filter emissions and avoid further land sealing.[26] Another possibility is intelligent waste management, which would not only reduce environmental pollution but also enable the reuse of resources.[27] On the other hand, smart environment includes an intelligent use of resources as well as the use of sustainable resources, especially in terms of energy consumption. This could be achieved through

[23] cf. Cohen 2015
[24] cf. Cohen 2015
[25] cf. Gassmann et al. 2018, p. 23
[26] cf. Gassmann et al. 2018, p. 23
[27] cf. Ejaz & Anpalagen 2019, p. 5

intelligent systems – in particular IoT – which enable an intelligent allocation of resources. For example, sensor technology can be used to control a street lamp lightning up when cars or pedestrians pass by only and stay switched off otherwise. This enables energy consumption to be balanced and energy to be consumed only where it is required.[28]

**Smart economy**

A city's economy is one of the main drivers of a city's wealth, as it influences the income of its citizens and provides the necessary tax revenue. Factors to be considered within the smart economy are efforts to promote innovation, new business models and talent, stimulate economic growth, boost productivity and intelligent integration into the international market. These initiatives are intended in particular to increase the city's competitiveness.[29] As a result, through intelligent technology a favorable environment for all businesses should be created and responsive regulatory policies that promote a smart and efficient economy should be ensured. Thereby, cities should be both, dynamic and seamless. As a trend example, innovation labs can be used which develop new and innovative solutions for social challenges and at the same time provide an efficient platform for collaboration.[30]

**Smart mobility**

Smart mobility is one of the key points in a Smart City, as people in cities must be able to move quickly and effectively between individual locations – nowadays congested traffic systems are a main reason why this is not possible at all times.[31] The future smart mobility will be based on digital systems such as IoT. Sensor technology will allow traffic systems to automatically adapt to changing conditions such as accidents or traffic jams and will enable intelligent parking systems to indicate the nearest parking space to users.[32] This will also include an intelligent pricing system that dynamically adjusts the price for the use of transport systems according to time, road conditions or other influences. In addition, digital platforms enable collaborative transport options such as ride sharing and apps that plan and manage the mobility of people using different transport options, transforming transport into a service. Another innovation that will significantly influence inner-city mobility is autonomous driving, which further optimizes traffic flow through connectivity, sensors and intelligent systems.[33] This results in the fact that the traffic system of the future will be a fully connected system which enables a more efficient transport system in terms of resource consumption and the reduction of emissions in urban areas.

[28] cf. Deloitte 2018b, p. 9
[29] cf. Gassmann et al. 2018, p. 29
[30] cf. Deloitte 2018b, p. 7
[31] cf. Gassmann et al. 2018, p. 30; Ejaz & Anpalagen 2019, p. 4
[32] cf. Deloitte 2018b, p. 7; Gassmann et al. 2018, p. 30
[33] cf. Deloitte 2018b, p. 7

**Smart government**

Under the aspect of smart government, the efforts which focus on how a city is organized and managed internally are summarized.[34] Efforts in this area should in particular improve and simplify the participation of citizens and increase the transparency of administration.[35] This includes digital citizen services (e-government), new digital concepts for decision-making and transparent political perspectives and strategies.[36] In addition, smart government uses the comprehensive data and digital analysis methods to be innovative. For example, through data analysis, fact-based investigation of social problems can be established. Furthermore, transparency, citizen participation and competition lead to more effective planning and problem-solving approaches based on feedback and creative alternatives that are introduced by the private sector. This generates innovative and low-risk solutions for future urban developments, which are accepted by the population due to transparency within the planning process.[37]

**Smart people**

The key factor in the transformation to a Smart City are the people living there. They need to be willing to contribute and share their knowledge with their community and to develop new concepts and systems.[38] The smart people dimension focuses on improving the human capital of a city by promoting education and creativity while ensuring a high level of collaboration between people at the same time.[39] In this context, smart education which benefits from the new technologies has an important function. Digital learning enables a significantly higher range of knowledge to be acquired and enables a user-specific learning program and pace, independent of time and place. By analyzing the specific learning data, the learning programs and techniques can be further developed and optimized, which in turn results in a higher learning success. This enables people to develop their skills for a lifetime. In addition, the interaction between the different institutions is encouraged, thus providing a more effective basis for new innovations.[40]

**Smart living**

As mentioned, the residents of a city are a very important factor for the development of a city. The characteristics of smart living addresses the safety, health and quality of life of these residents as well as the culture within a city and the smart infrastructure with connected buildings.[41] People benefit from intelligent technologies like (predictive) data analyses which, for

[34] cf. Gassmann et al. 2018, p. 33; Ejaz & Anpalagen 2019, p. 4
[35] cf. Gassmann et al. 2018, p. 33
[36] cf. Gassmann et al. 2018, p. 33; Ejaz & Anpalagen 2019, p. 4
[37] cf. Deloitte 2015, p. 76
[38] cf. Kogan & Lee 2014
[39] cf. Gassmann et al. 2018, p. 35
[40] cf. Deloitte 2015, p. 67
[41] cf. Apanaviviene et al. 2020, p. 2; Deloitte 2018b, p. 8

example, optimize their energy consumption and its related costs or help them to improve their decision-making.[42] Moreover, the police is supported by new data-based technologies, such as geo-spatial analysis, which allows the visualization of child misuse or drug abuse, resulting in increased safety for the residents. People's health is also positively affected, as the health care system is being digitized and portable devices record all health data, evaluate them and indicate possible health risks in advance.[43] Furthermore, the tourism of a city can be improved, for instance by digital city or museum tours.[44]

### 2.1.5 Use cases of Smart City concepts

There exist many Smart City projects all over the world. In the following chapter various sub-concepts of individual projects will be described to provide an overview of the comprehensive possibilities of a Smart City.

**Amsterdam, Netherlands – Smart grid**

A comprehensive smart grid was installed in the Nieuw-West district of Amsterdam. For this purpose, the 10,000 households are networked and smart meters and sensors are integrated in buildings and in network intersections. This enables all consumptions and power inputs to be monitored and controlled centrally. With this system, electricity production can be precisely adapted to consumption, power consumption can be optimized and power failures can be prevented in advance. In addition, the installation of sustainable power generation systems such as photovoltaic (PV) systems or heat pumps can be controlled in a better way and integrated into the overall system. The end users can benefit from the smart grid as well. They can check whether it is cheaper for them to supply energy to the grid or to store it in real time.[45] In this context, a key component is the virtually power plant, which was specifically implemented in the district Nieuw-West. This is an online platform in which the consumption and production of solar energy is displayed digitally. Surplus available energy is stored in installed batteries in the residential homes. A significant added value of the system is that it enables private consumers to offer their electricity on wholesale markets if the price is considered profitable. However, in which dimension the online platform can support the network in peak times, needs to be examined in long-term tests, but the prerequisites have been fulfilled.[46] In summary, the smart grid leads to sustainable power consumption and to more balanced and optimized overall system.

[42] cf. Deloitte 2018b, p. 8
[43] cf. Deloitte 2018b, p. 8; Gassmann et al. 2018, p. 25
[44] cf. Gassmann et al. 2018, p. 25
[45] cf. Zeeb 2018
[46] cf. Bosch 2018

**Auckland, New Zealand – Dynamic traffic lanes**

Auckland, like many other big cities, has traffic issues during peak hours. For this reason, the city administration is developing new transport concepts to ensure traffic flow. One example is the implementation of dynamic lanes. The system decides in which direction more lanes are needed based on the traffic volume. The background is the fact that the traffic in the peak hours usually runs in one direction only – in the morning towards the city center, in the evening from the city to the suburbs – and thus one direction of traffic is congested and the other direction is insufficiently used. With the dynamic lanes, during peak hours more driving lanes are allocated for the direction with a high traffic volume. These can also be adapted to certain traffic incidents such as accidents. Consequently, the traffic flow is optimized, the space utilized for roads is improved, traffic jams and loss of time for residents are avoided and therefore welfare losses are minimized.[47] Such project examples have already been implemented in Auckland at the Panmure Bridge, Auckland Harbor Bridge, and Whangaparaoa Road.[48]

The concepts in Auckland are tied to roads that are used exclusively for motorized traffic and are fixed to certain times. In order to make such concepts even smarter, it is conceivable that the system could use the data provided to decide lane allocation, as the peak times are not always equal. In this context, it would be possible that individual lanes are only allocated to buses at certain times. In addition, a mixed concept with bicycle lanes or pedestrian zones would be plausible as well. For example, in the morning an intelligently designed pedestrian zone in the city center could be used as a mixed bicycle and car traffic route. This area would be transformed back into a pedestrian zone and shopping arcade at a certain time of the day. Hence, the use of space can be optimized and traffic can be improved. Thereby, it is important that the system can continue to learn independently and thus adjust the traffic flow autonomously and absolutely dynamically.

**Barcelona, Spain – Smart people initiatives**

Barcelona wants to establish a co-creation network for the further development of the Smart City by involving citizens as much as possible. Since many people in Barcelona do not have the skills to participate, the Fab Labs, which are part of the Institute for Advanced Architecture of Catalonia, was established.[49] In the Fab Labs, people can "learn about the principles, applications and implications of digital manufacturing technology"[50]. Thereby people should get access to the knowledge, tools and technology to be innovative and to participate in the design process of the Smart City without spending high costs. For those residents who have already

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[47] cf. Auckland Transport 2020a
[48] cf. Auckland Transport 2020b
[49] cf. Fab Lab Barcelona 2020; Smith 2020a
[50] Fab Lab Barcelona 2020

established the necessary skills, Barcelona has created 22@Barcelona. The objective of the initiative is to create an innovation hub that connects talents and maximizes the use of data within the city to develop new technologies. In the process, the Barcelona community will be connected to the worldwide community, which has already led to several project successes.[51]

**Copenhagen, Denmark – Data driven infrastructure design**

In a Smart City, not only daily processes can be intelligently managed, but also a design process. For example, the infrastructure can be smartly organized to optimize the overall benefit. The city of Copenhagen demonstrates this with several projects. As an example, the infrastructure decisions from 2011 for the Queen Louise's Bridge can be considered. For this project, sensors were installed in 2009 which measured traffic over a long period of time. As a result, it was found that the bridge is crossed every day by more than 12,000 bicycles and only by 7,300 cars. However, the bridge was designed for a higher car traffic, two car lanes in each direction, but only a 1.8m wide bicycle lane for both directions. Consequently, the layout of the road was adjusted on the basis of the collected data. Today, there is only one vehicle lane per direction of travel, one bicycle lane in each direction with a width of 4.0m and a large pedestrian walkway. The result is impressive. The new design has reduced car traffic by 57% and increased bicycle traffic by 60%. At the same time accidents were reduced by 45%. Moreover, today the bridge is not only a traffic route but also a public place where people meet. A multiuse space has been created. As a result of the projects in Copenhagen it can be stated that a data-based decision-making process enables to find a people-centric design. The process is plausible for the population and allows them to participate in shaping it. This creates transparency and acceptance, in contrast to traditional political decisions.[52]

**Helsinki, Finland – Underground waste management**

In Kalasatama, a district of Helsinki, a Smart City is emerging from the former harbor area. A central component of the concept is the intelligent waste disposal system. The district does not need waste containers or trash trucks in the future, since the community is linked to an underground waste system. For this purpose, kilometers of pipes were installed in the town's ground. Residents put their rubbish into an above-ground tube entrance, whereby it is separated according to five possible types of waste. Afterwards, the underground pipe system uses vacuum to transport the waste to a central collection point where it is further processed. Thus, smell and noise in the city are avoided as well as traffic is reduced, resulting in fewer emissions and providing a more livable city.[53]

[51] cf. Smith 2020a
[52] cf. Bakker 2020a, pp. 125-137
[53] cf. Drammeh 2020; Fagan 2019

However, the district Kalasatama was completely rebuilt. This allows to integrate such a system. In existing cities, the integration of this kind of system is very costly and difficult to achieve during normal operation. Therefore, the system is an innovative solution for completely new districts to be built, but in existing districts other intelligent concepts should be considered.

**Palo Alto, USA – Smart parking system**

One possible reason for unnecessary driving is the search for parking spaces, which can cause additional traffic and thus traffic jams as well as it leads to more emissions. The simplest way to prevent this is to guide the driver to the nearest parking lot as quickly as possible. Therefore, the city planners in Palo Alto introduced an intelligent parking system. The core of the concept are sensors that detect whether a parking space is occupied. This data is collected in a cloud and enables searching drivers to determine the location of the nearest parking space via an app. In this way, the driver can find the best possible parking spot without unnecessary driving. This will result in a reduction of traffic and will enable a more efficient use of parking spaces. Furthermore, the number of parking spaces provided can be optimized over time and unnecessary parking spaces can be used for other purposes.[54]

**Santander, Spain – Smart Irrigation and smart garbage bins**

In Santander, garbage transport used to be one of the highest expenditure units of the city administration. Therefore, an intelligent waste system was established. Sensors in the waste bins detect whether the bin is full and must be emptied. This data is transmitted to the garbage collection service, allowing only those garbage cans to be emptied that are full. Thereby the routes are always planned as economically as possible, whereby the costs for the garbage collection could be reduced by about 25%.[55]

Another initiative in Santander to achieve both economic and ecological advantages is the integrated irrigation system. Public green areas are equipped with sensors that measure the soil hydration. The data obtained is analyzed and compared with weather forecasts. As a result, artificial irrigation is only used if the earth is too dry and no natural irrigation is announced. This enables an optimized water consumption.[56]

**Seoul, South Korea – Smart subway system**

Seoul had almost ten million inhabitants in the year 2019.[57] This causes a great challenge for the transportation system to ensure that people get from place A to place B quickly and easily.

[54] cf. Smith 2018b
[55] cf. Louven 2018; Vogt 2017
[56] cf. Körzell 2018; Vogt 2017
[57] cf. Population Stat 2020

To provide the necessary services, an intelligent subway system was implemented in Seoul. The system is based on continuously updated information. Turnstiles are used on the one hand for payment and on the other hand for monitoring the number of people in the subway stations. Also, cameras are used to monitor how many people board a particular train or are on a subway line. This data is collected and analyzed centrally. Through the data analysis, schedules are adjusted in real time and it is possible to identify which stations require more staff and which routes require a higher frequency or speed of trains. This means that the range of transport can be increased exactly where it is needed and thus optimize the overall system. In addition, the trains are equipped with various sensors that analyze the condition and enable predictive maintenance to avoid major and costly outages. As a result, the intelligent system in the Seoul subway ensures that the daily eight million users can be handled and that the transport system runs continuously.[58]

**Singapore – Mobility as a service**

In order to become a car-lite society, the authorities of Singapore are promoting public-private-partnerships for developing new models of mobility. In the process, comprehensive data on taxi services, traffic data and parking space availability are collected and provided anonymously to the innovators and citizens. Through data analysis, new models for mobility are supposed to be achieved; up to now, already overused bus lines have been de-stressed. In the future, alternative transport options should be created and the previous mobility should be transformed into mobility as a service. This means that the end user is provided with the optimal transport option based on data and the specific requirements of the consumer. Various solutions have already been developed. For example, the app "Happy-Wheels" allows wheelchair users to find a route or service for transport within the city.[59] In the future, self-driving robotic buses or taxis are to become a central component of the mobility as a service concept. These will reduce private car traffic to a minimum. Currently, these robotic vehicles are undergoing testing in the One-North district and are scheduled to go into operation in 2022 at the latest.[60] Obviously, the traffic in Singapore is clearly going to change, some concepts have already been developed, but how the concept mobility as a service will be further developed will be shown in the next years.

**Songdo, South Korea – Next level of digitization**

On the west coast of South Korea one of the most comprehensive versions of a Smart City was built. Songdo has been completely rebuilt and is intended to become the pioneer in networking in Smart Cities by using the extensive technological possibilities. The core of the

[58] cf. The Economist 2017
[59] cf. Smith 2018c; Vertech Capital 2018
[60] cf. Harloff 2018

project is the digital twin (see Chapter 3.3), which is intended to be as comprehensive as possible through the integration of education, public administration, supply networks such as electricity, etc. Thereby the complete infrastructure including the residential and office buildings is networked. Data is obtained from public cameras, from networked transport infrastructure or from the measuring units in buildings regarding electricity, heat, light etc. All generated data is collected centrally within the administration and analyzed in the digital twin. The self-thinking city has many advantages for public life. For example, energy consumption can be reduced to its optimum or extremely high reaction time in case of accidents enables traffic benefits. Songdo residents can use digitization technology not only to completely control their homes, but also to access digital education, use the digital administration system, or use the housing system as a schedule or task manager. Companies can access all generated data of the city to develop or verify new innovations or business models. The described type of implementation is possible in particular through the support of the government. For example, obstacles concerning data protection, which can be identified as a major obstacle in other countries and cities, had been overcome by specially developed laws for Songdo.[61]

However, Songdo City has not been able to meet the expectations yet. Although many South Korean residents can be described as technophile, even in this place complete networking and the associated monitoring is not always popular. Consequently, the city currently has fewer inhabitants than anticipated and therefore the streets and public spaces seem empty and not optimally used today. In addition, the city will not reach the originally planned construction dimensions, the mobility concept on a sustainable basis with the core of public transport – there are many multi-lane roads – has not been fully achieved and only one third of the total urban area has gained LEED certification. As a result, the entire city still has to develop in order to take advantage of the extensive possibilities and this example demonstrates that not all desired Smart City approaches can be implemented today.[62]

**Toronto, Canada – Example for a failed project**

In 2017, Sidewalk Labs, a subsidiary of Google, obtained the right to build a Smart City in a district of Toronto with a size of 49,000 square meters. More than 3,000 residential units were planned with a comprehensive Smart City concept. Wood should be used as a sustainable building material, electricity should be generated from solar energy, heating should be provided by geothermal energy, garbage should be removed by underground robots, heated bicycle paths should allow safe cycling even in winter or with AI an intelligent mobility concept should

[61] cf. Gassmann et al. 2018, pp. 112-120
[62] cf. Gassmann et al. 2018, pp. 112-120

have been developed. Sidewalk Labs has invested over 50 million US dollars until 2020. However, in 2020 the project was declared to have failed.[63]

In the official statement, the failure was justified with the Covid 19 pandemic. According to Sidewalk Labs CEO Dan Doctoroff, “as unprecedented economic uncertainty has set in around the world and in the Toronto real estate market, it has become too difficult to make the 12-acre project financially viable without sacrificing core parts of the plan”[64]. However, if the project had been considered profitable in the medium term, the project would have been financed even through this difficult phase, as these are promising concepts for the future.[65] Reasons for the failure can be found since the beginning of the project. Repeatedly resistance from the political community arose, with the large number of representatives from the local, provincial and federal government claiming the right to take part. At the same time, many city planners wanted to prevent a situation in which the design of cities will be created by technology firms in the future. The Canadian technology companies demonstrated resistance to the project managed by American companies as well. Moreover, the project was repeatedly confronted with data protection problems – not least because Canadian citizens did not want their data to be controlled by American companies. The critical fact was that the technology used was particularly intended to infringe on the personal rights of the residents. In summary, the reasons for the failure of the project are much more diverse than just the Covid 19 pandemic.[66]

Based on the various reasons for the failure of the project, lessons learned can be derived:

- Rethinking the function of private technology firms
- Education of digital skills within the government
- Development of a framework for handling data and data ownership before the start of the project
- Establish a well-defined task allocation within the project phases
- Creation of transparency and involvement of residents[67]

**Vienna, Austria – Smart collaboration**

In order to remain one of the most livable cities in the world, Vienna wants to involve its inhabitants in the future Smart City development themes. All citizens should be informed about the entire process and should also be able to contribute their ideas. For this purpose, so-called stakeholder forums were established. For example, there are information events that report on the status of the project or work phases in which the possibilities for action and design are

[63] cf. De Vynck & Wong 2020
[64] Doctoroff 2020
[65] cf. McGrath 2020
[66] cf. De Vynck & Wong 2020
[67] cf. Haggart & Tusikov 2020

evaluated. The content of these meetings is always digitally provided to the people to enable them to have access to all necessary information. After the forums, the city of Vienna offers a variety of cooperation possibilities which should encourage the inhabitants to participate actively in the processes. Consequently, Vienna will become an open innovation platform, whereby the entire community will be involved in the innovation process. This will generate a large number of ideas which will be realized in Vienna through the establishment of co-creation labs.[68]

An exemplary technology for the involvement of citizens is the app "Sag's Wien", which was designed in cooperation between citizens and city administration. Residents can use the city's app to communicate a wide variety of concerns, such as hazardous areas. Thereby the platform ensures continuous interaction between citizens and authorities, which creates an exchange without bureaucratic obstacles. In addition, this also shows one way in which the digital twin can be expanded through communication by people.[69]

Within this chapter it is obvious that there are many different concepts within a Smart City. There are many other ideas that have been implemented in cities around the world and often the described practical implementation possibilities have been realized in other cities as well. The mentioned approaches provide an overview of the holistic concept of a Smart City and are not exhaustive. However, for the concept to be developed in this thesis all ideas collected during the literature research are taken into account.

## 2.2 Smart Buildings

Smart Buildings can take a core function in Smart Cities, as they can influence the overall system through ICT and buildings are a major part of the infrastructure of cities. Therefore, the following chapter explains the concept of Smart Building and provides examples of projects.

### 2.2.1 Definition and goals

A Smart Building aims to optimize the quality and design of the building through higher efficiency, sustainability and productivity, reduces life cycle costs and provides a healthier and more comfortable working environment for users.[70] For this purpose, the entire life cycle of the building is optimized. Sustainable materials appropriate to the location and sustainable technologies are used for the construction of the building.[71] The building is equipped with IoT, which allows the technical components to exchange data in real time and to collect and analyze all

[68] cf. Gassmann et al. 2018, pp. 65-66
[69] cf. Gassmann et al. 2018, p. 66
[70] cf. Bakker 2020a, p. 97
[71] cf. Apanaviviene et al. 2020, p. 4

kinds of relevant building data. Furthermore, preferences of the users are integrated into the overall system of the building through digital devices such as smartphones. This system allows buildings to control their operations such as heating, ventilation, cooling, etc. automatically and to introduce predictive maintenance systems, which ensure the building operation.[72] Thereby, the building can adopt its behavior to the changes in its inside and outside environment. In this process, the building learns from each new experience, which improves the decision-making process of the system.[73] This leads to an optimized use of space within the building and to an optimized building operation with regard to ecological and cost aspects. The result is a building that automatically optimizes its productivity, performance, environmental impact and comfort.[74]

### 2.2.2 Projects

In the following chapter realized Smart Building projects are described. Thereby both, office and residential buildings, are considered.

**The Edge (Amsterdam, Netherlands)**

The Edge is an office building of the consulting firm Deloitte in Amsterdam, which was completed in 2014.[75] According to BAKKER – developer and architect of The Edge – the building "set(s) new standards in sustainability, technology, workforce interaction, flexibility and user experience, and shows how Smart Building design can reduce energy demands"[76]. The Edge is often called the smartest building in the world (e.g. by Randall 2015, World Economic Forum 2017), at the same time it is the most sustainable building in the world measured by the BREEAM rating. Intelligence can be found in the building's architecture and design as well as in the integrated technologies that enable the optimization of building operation in terms of heating, cooling, etc. and ensure the smart and efficient use of the available space.[77]

With a BREEAM rating of 98.36%, The Edge is the building with the highest recorded rating, making it the most sustainable building in the world.[78] Thereby the intelligence of the building starts with architecture. The Edge has a north-facing glass facade, providing access to natural lighting for more than half of the workspaces. On the south side, concrete was used to absorb as much heat as possible. In addition, PV systems were installed on the south side wall and on the roof to enable solar energy to be used for the building. Moreover, the consumption of resources is sustainable. The entire heating and cooling system is powered by an aquifer thermal energy storage system, in which only the pumps need input energy. LED Ethernet-

[72] cf. Bakker 2020a, pp. 97-98
[73] cf. Apanaviviene et al. 2020, p. 4
[74] cf. Bakker 2020a, pp. 97-98
[75] cf. Bakker 2020a, p. 113; World Economic Forum 2017, p. 14
[76] Bakker 2020a, p. 113
[77] cf. Bakker 2020a, pp. 113-123; World Economic Forum 2017, pp. 14-17
[78] cf. World Economic Forum 2017, p. 15

connected lightning system not only saves electricity but also reduces material consumption. Flushing toilets or irrigation of plants is done by rainwater which is collected on the roof and balconies. In addition, the building can exactly monitor the consumption via the installed sensors, explained in detail below, and thus optimize the operation.[79] As a result, the energy consumption of the building is net negative, which indicates that the building produces more energy than it consumes.[80]

A core element in the development of the building concept were multidisciplinary teams, which also included experts from suppliers. This allowed 21 innovations which were not yet used in previous buildings to be integrated into The Edge.[81] According to BAKKER, the most forward-looking innovation is Philipp's Ethernet connected lightning.[82] As mentioned, these lightning on the one hand saves energy and reduces material consumption. On the other hand, the lightning contains sensors, which enables the measurement of light, temperature or moving of people, and the LED is able to network with the whole building system. The 6,000 LEDs together with 28,000 additional installed sensors in the building enable smart facility management based on data analytics. All areas are cleaned on the basis of their use. For instance, towel dispensers can detect when they are almost empty or by monitoring the various systems, predictive maintenance is possible. Furthermore, the sensors allow monitoring energy consumption in order to optimize the overall system.[83] In addition, robots are used in the building to patrol the building at night or to clean the floor surfaces.[84]

In traditional office buildings, often 50% of the workplace is not used during the day. In order to avoid such situations, a flexible workspace concept was integrated into the building. Employees in the building can use a specially developed app to indicate which specific workstation (meeting room, standing desk, sitting desk, etc.) they require at a particular time. Based on their needs and occupancy, the building allocates a workspace to each person for a specific time. This enables 2,500 employees to share 1,100 workstations or, in order to save energy, certain areas stay completely empty when there is less occupancy. At their workplace, employees can adapt their working environment to their specific needs in terms of ventilation, heating and lighting and thus optimize their user experience. In the process, the building learns every day and can directly take into account the preferences of the employees with regard to space requirements or working environment.[85] Since the building knows where everyone is at every time, the app can also help to find a colleague who is needed. In addition, as the building

[79] cf. Bakker 2020a, pp. 116-117; World Economic Forum 2017, pp. 14-15
[80] cf. World Economic Forum 2017, p. 15
[81] cf. Bakker 2020a, p. 119; World Economic Forum 2017, p. 14
[82] cf. Bakker 2020a, p. 119
[83] cf. World Economic Forum 2017, p. 14
[84] cf. Randall 2015
[85] cf. Bakker 2020a, p. 120; World Economic Forum 2017, p. 15

was designed during the economic crisis of 2009, increased flexibility had to be taken into account so that if less space was needed, the building could also be used for other purposes. Hence, the building can be converted into a university without high expenses for example.[86] Consequently, the intelligent space concept optimizes the use of the available space, improves energy consumption and strengthens the exchange of information between employees, since different employees sit next to each other every day.

In summary, through the consideration of wishes and needs, an extraordinary and a user-centric building was created. The design and operation of the building helps Deloitte to create a collaborative working environment in which employees form a huge communicative community. In addition, the involvement of suppliers enabled the company to implement new innovative technologies. As a result, although The Edge is the most expensive office building per square meter in the Netherlands, it is also the cheapest per used employee.[87]

**PTK1 (Petah Tikva, Israel)**

Since its completion in 2019, Intel's PTK1 has been competing with The Edge for the title of Smartest Building in the world. The building combines smartness and sustainability just like The Edge. A unique design process was used to maximize the user experience and to create an innovative, collaborative working environment. The focus was on scalability to allow the concept to be adopted in other buildings through a process of standardization.[88]

In order to focus on the needs of the employees, the agile working method Design Thinking was applied in the development of PTK1. Thereby the building was considered from a user perspective in order to derive different needs. For this purpose, workshops were organized with more than 250 employees, in which daily activities and processes of the employees had been determined. Within this process, nine different user journeys and over 300 different use cases for behavioral scenarios were identified. Based on these use cases the building was designed, even if only 180 of the 300 use cases were considered in the current building due to technical possibilities, privacy and data security.[89]

During the design process various concepts were considered to ensure that the building is highly sustainable. 100% of the energy consumed within the building is provided by renewable energy and within the building a sophisticated water management system is used to minimize consumption. The facade was built double-skinned to absorb heat from outside and therefore

[86] cf. World Economic Forum 2017, p. 16
[87] cf. Bakker 2020a, pp. 120-123; World Economic Forum 2017, p. 17
[88] cf. Intel 2020; Intel 2019; Wray 2019
[89] cf. Intel 2020

reduce the necessary cooling. In the construction process, mainly renewable materials were used and 95% of the building debris was recycled. As a result, the building is 40% more energy efficient compared to ordinary office buildings and uses 75% less water, thus achieving the LEED Platinum certificate.[90]

At PTK1, more than 14,000 sensors are used, which collect data about temperature, light or people movement. Thereby the sensors gather over 50 terabytes of data every day. In the process AI is used for analyzing the provided data. This allows the monitoring and controlling of building systems like cooling, room availability or lighting. Therefore, sensor technologies enable smart operation, maximize efficiency and allow continues improvement of the user experience. The sensor technology used is comparable to the technologies in The Edge, but when integrating and creating the connectivity in PTK1, the focus was on the scalability and reusability of the building concept. Because of this, far fewer sensors are built into PTK1 (14,000) than in The Edge (34,000). However, comparable intelligent building operation can be achieved with the lower number of integrated sensors.[91]

Through the integration of intelligent technologies and through the user-centric design many operations can be identified in PTK1, which simplifying daily life for the user. Everywhere in the building digital touch screens are installed, which help the users with dining options, transportation status or way finding. At the workstations there are various possibilities to adapt one's working environment. For instance, smart lightning enables users to adapt the light to a specific thinking process, or meeting rooms are equipped with a wide range of options to realize privacy or creativity in a number of different settings. Smart parking allows the system to determine occupancy via sensors and cameras and thus direct the drivers to available spaces. Moreover, after work the system guides the drivers to the car location. Transport to and away from the workplace can significantly complicate the life of employees. For this reason, a smart transportation system was integrated into PKT1 as well. Employees are provided with the best routes and transport options via displays. A central part of the system is carpooling, which allow employees to react flexible to traffic and probably to share cars with other members, which not only reduces the amount of underground parking space required but also optimizes car utilization. In addition, as mentioned above, the building learns every day. For example, this allows the system to inform employees about the best time for their lunch on the basis of occupancy. Taking these different sub-concepts into account, the whole building is designed to optimize the time consumption of employees and thus maximize the user experience.[92]

[90] cf. Intel 2019; Wray 2019
[91] cf. Intel 2020; Intel 2019
[92] cf. Intel 2020; Intel 2019

In summary, in PTK1, modern and smart technology enables a sustainable and user-optimized building similar to The Edge. Intelligent space management was not integrated in PTK1, but workplaces with creativity options were introduced to promote innovative work. A linked transport system could be integrated as well, which enables carpooling and thus optimizes the use of space. Furthermore, a concept could be created which can be applied to other buildings.

**Ausblick (Hartenfels, Germany)**

In collaboration with the technology group IBM, HUF Haus, a German company specializing in prefabricated houses, has presented the world's first self-learning home named “Ausblick” in 2018. The model house is provided for customer attendance in the Hartenfels model park. Through the IBM Watson Platform, the model house learns from human behavior patterns, which basically distinguishes it from common smart home solutions.[93]

In Ausblick, the building's intelligence starts with the construction. The bungalow is made of glass and wood, whereby the construction can be considered innovative and revolutionary. A self-developed connector allows the glass elements to be integrated into the wooden construction exclusively by mechanical means; previous constructions always required a chemical adhesive.[94] Furthermore, the building heats by an air-heat-water pump, which avoids the use of non-regenerative resources.[95]

The model house Ausblick differs fundamentally from other smart home solutions, which only execute static processes. The house can recognize behavioral patterns through voice commands or through facial recognition of assigned behavior of the residents. This information is processed by AI software, making an autonomously learning process possible. This enables the house not only to open the front door for residents using facial recognition, but also to perform typical activities such as brewing coffee automatically after getting up or to adapt the room atmosphere to the requirements of the user in terms of lighting and temperature. Therefore, the building learns how to continuously improve the comfort of the residents and if necessary to adapt to new situations or preferences. In this context, the control always remains in the user's domain, who can command the building to replace information. Communication can take place via input on a touch display or by voice command. In order to enable communication as natural as possible, the digital assistant from IBM was integrated, which enables personalized support. Furthermore, a small robot was installed inside the building which can assist the resident if desired. The intelligence of the building can also be used to optimize resource consumption. Electricity and heating consumption are monitored and analyzed by IoT and AI

[93] cf. HUF HAUS 2018, p. 1
[94] cf. HUF HAUS 2018, p. 1
[95] cf. HUF HAUS 2020

solutions. The provided data is correlated to current weather conditions, which allows continuously improvement of consumption. The model house has been tested in real conditions. The test subjects were the employees from the marketing team of HUF Haus, who presented the house to customers in their daily work and used the building partly as an office as well.[96]

To ensure the privacy of residents and customers, particular attention was given to data security. The IBM EU cloud model ensures the highest level of data security. Data always remains the property of the homeowner and data used by AI solutions to learn is only processed anonymously.[97]

With the model house in Hartenfels, HUF Haus not only manages to provide its customers an attractive smart home. They showed how an innovative and sophisticated building, which optimizes the comfort of the occupants, can be designed through the cooperation of a technology group and a prefabricated house company.

**Privately developed Smart Home (Hauzenberg, Germany)**

In Hauzenberg, a Smart Building was constructed that differs from the previously mentioned use cases, since it was developed by the owner of the building and not by large technology or construction firms. The concept of the building is to combine the conventional goals of Smart Building comfort and safety with the central smart aspect – intelligent control and management. The key factor in this context is that the building is able to think based on continuous learning.[98]

To enable intelligent management and control within the building, AI applications were integrated. The house learns from the past, recognizes patterns through logic and can therefore think for itself. Thus, the building knows without direct intervention of the user what he needs. In this way, not only clearly defined scenarios are performed as in previous smart home applications, but the house decides which actions are necessary depending on the specific situation. An example of the use of intelligence is leaving the building. By moving away from the house, the house locks itself automatically and decides without direct request which functions are still needed in the house. For example, irons or lights are switched off, windows are checked to see if they are still open and the heating is operated in order that the correct room temperature is reached when the user enters the house again, otherwise it runs in energy saving mode.[99] Further examples are listed below, but the overview is not exhaustive:

– Garden is automatically watered based on weather data and soil moisture

[96] cf. HUF HAUS 2018, pp. 1-2
[97] cf. HUF HAUS 2018, p. 3
[98] cf. Heidary 2020
[99] cf. Heidary 2020

- House detects by ultrasonic sensors in the sewer whether there is a danger of flooding
- Children can play and learn with the house as apps can be installed[100]

Communication between user and building, which is necessary for the learning process, takes place in two ways. On the one hand, communication is performed explicitly by voice command or by data input in tablets or smartphones. On the other hand, there is indirect communication, for example by recognizing movement patterns with sensors. A further step in this process is that the house can also use facial expressions and gestures to derive a person's mood and react to it. Although the house contains many applications, it causes less electro smog than ordinary smart homes, because communication is wired and the integrated bus systems allow only those systems to be switched on that are needed in the specific situation.[101]

The planning of the house was comprehensive and focused on intelligence. For example, detailed planning made it possible to minimize the waste of tiles, thus saving material and costs. In addition, intelligently planned communication meant that individual sensors were reducible. For instance, in previous buildings sensors are usually attached to windows to detect if they are open. In the building in Hauzenberg, these are not needed, as the house detects whether windows are open through the interaction of ventilation rotation and pressure in the rooms. This indicates that the concept is more comprehensive than many other use cases.[102]

According to owner HEIDARY, a core element of his concept is energy management. In order to achieve the highest possible benefit from an energy point of view, a combination of different smart controlled components is used. The size and orientation of windows and PV systems have been designed to optimize their impact on energy management during the operating phase. An intelligent sun management system calculates the angle of the sun every ten seconds. This enables the slats and blinds to be aligned with millimeter precision, minimizing direct sunlight into the house and at the same time providing maximum natural light within the building. The ventilation system adjusts its ventilation speed in summer according to the outside temperature in order to maximize the amount of fresh air entering the house at the most favorable outside temperature. Since the building always knows where the residents are located – through movement sensors inside the building and through smartphones outside the building – heating can be targeted at the right place and time to reduce energy consumption while always ensuring comfort in real time. As a result, a passive house standard could be achieved from the originally built KFW 55 house due to the smart controlled energy management based on software and not through additional construction measures. Thus, additional construction

[100] cf. Heidary 2020
[101] cf. Heidary 2020
[102] cf. Heidary 2020

costs of about 75,000€ have been saved and the energy consumption in the operation of the building are reduced by 3,000 kwh per year, which results in economic and ecological advantages. Since a significant amount of money can be saved by the intelligence of the building during the operational phase, the additional hardware costs can be amortized over a period of 15 to 20 years while ensuring comfort and security as well. In addition, the environment is protected, since building materials that would be required for a passive house standard are harmful for the environment, as these materials contain much more grey energy than conventional building materials, which often cannot be amortized over the life cycle of the building.[103]

A multifunctional room is located in the basement of the building. In this room, ventilation, heating and light can be adjusted to allow different types of use, such as guest, fitness or cinema room. This results in a multi-purpose use which optimizes the utilization of otherwise less used space. Furthermore, the optimal use of space over the life cycle of the building was taken into account. The floors were designed in such a way that they can be separated spatially, mechanically and electrically from each other without major structural intervention. Thereby, the smart home applications of the different floors can operate autonomously. This allows, for example, if less space is needed due to children moving out, to occupy only one floor and rent the others. This optimizes the use of space over the life cycle, resulting in economic advantages.[104]

To sum up, one could say that through ideation, creativity and willingness combined with entrepreneurship and knowledge, HEIDARY changes the way on how we should plan, design and make buildings smart in order to link comfort and safety of residents with smart control and management. Thereby, detailed planning is identified as a key point for the creation of a Smart Building concept in order to design an intelligent system based on the given boundary conditions and circumstances.[105]

## 2.3 Integrate Smart Buildings in a Smart City

Creating an interaction between Smart City and Smart Building is important, as Smart Buildings can influence other buildings or other infrastructure components on the basis of environmental changes and thus become a consistent element of the environment.[106] This leads to further optimization in various areas. For this reason, the following chapters deal with the Smart Building integration into the Smart City concept.

[103] cf. Heidary 2020
[104] cf. Heidary 2020
[105] cf. Heidary 2020
[106] cf. Apanaviviene et al. 2020, p. 4

### 2.3.1 General requirements and levels

Smart Buildings can influence a Smart City in several ways. For instance, interaction enables it to create microgrids to compensate fluctuations in the power supply system and thus optimize overall energy consumption. This allows a building to adapt its energy consumption to the overall system in real time. Moreover, buildings collect a lot of data about the people inside. This can be used by the overall system, for example to improve mobility, as more comprehensive data about the current demand is available. As a result, it can be stated that Smart Buildings can be the main component to develop a Smart City by networking with the city.[107]

In principle, buildings must be connected to the city via a network in order to integrate Smart Buildings into a Smart City. This network has to enable the exchange of real-time information.[108] As a second requirement, it can be deduced that both, the buildings and the city, must be equipped with IoT technologies for the purpose of collecting data and creating the prerequisites for analysis, learning and further optimization.[109] In addition, the cities as well as the buildings must implement technologies to analyze and evaluate the data within themselves. By interacting on relevant data, cities and buildings can optimize the overall system.[110] Based on these findings, APANAVIVIENE (2020) has derived levels, which indicate the requirements to further enhance the interaction between city and building. These levels are shown in Table 1.

| | **Smart Building Integration Levels** | **Level Description** |
|---|---|---|
| Level 1 | Ability to network (system and subsystem) | Connection to a wired or wireless network |
| Level 2 | Ability to see information (real time) of the other components | Response to any change in the environment or traction of the amount of a given data stream |
| Level 3 | Ability to collect information (historical) | Collection of information with the potential to share or use it in the future |
| Level 4 | Ability to process information (analyze) | Analysis of information received for the appropriate actions |
| Level 5 | Ability to make decisions (report) | Evaluation of the resulting analysis and report on changes |
| Level 6 | Ability to compare baseline (evaluate) | Conclusion based on analysis over a period of time |
| Level 7 | Ability to validate over time (trend) | Introduction to trends, technological development, continuous and reliable improvement |
| Level 8 | Ability to control (act) | Autonomous decision-making and remote control |

*Table 1: Integration levels of Smart Buildings in Smart Cities*[111]

[107] cf. Forbes Insights 2018
[108] cf. Apanaviviene et al. 2020, p. 15
[109] cf. Teubner, S. 2018; Apanaviviene et al. 2020, p. 15
[110] cf. Apanaviviene et al. 2020, p. 15
[111] own illustration based on Apanaviviene et al. 2020, p. 15

The different levels in Table 1 should be considered specifically for each Smart City segment in order to derive which technologies are needed segment-specifically to meet the requirements. Often these are not generalizable, since commonly integrations are based on city specific prerequisites and a uniform standard does not exist for all segments so far.[112]

### 2.3.2 State of development of existing projects

The research of APANAVIVIENE ET AL. analyzes specifically the degree of integration of Smart Buildings in existing Smart Cities.[113] For this purpose five different segments were investigated. These differ from the segments defined in Chapter 2.1.4. However, this approach is still suitable to affiliate concrete potentials. Figure 3 illustrates the results of the research paper.

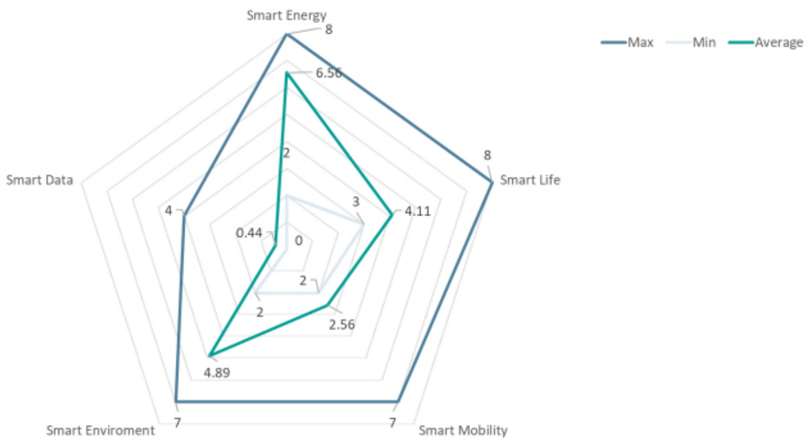


*Figure 3: State of development of integration of Smart Buildings in Smart Cities[114]*

Figure 3 shows that integration is most advanced in the areas of smart energy (Ø 6.56) and smart environment (Ø 4.89). This is due to the fact that in recent years the focus has been increasingly on the environment in terms of resource and energy optimized construction and operation. The third area is smart living (Ø 4.11), which is already well advanced, primarily through the invention of new technologies that people use every day as well as through new smart components that are installed in buildings. Furthermore, the study assumes that the segments smart environment and smart living have the highest growth potential based on already existing technologies and project examples. The segments smart mobility (Ø 2.56) and smart data (Ø 0.44) are obviously not used sufficiently. Nevertheless, according to

[112] For an example standard, it can be stated "Ready to Services" (R2S) or "Ready to Grid" (R2G) regarding the segment smart mobility from the Smart Building Alliance (SBA)
[113] cf. Apanaviviene et al. 2020, p. 15
[114] own illustration based on Apanaviviene et al. 2020, p. 15

APANAVIVIENE ET AL., these two segments will be upgraded in the next few years by developments in the areas of AI, IoT and other new digital technologies.[115]

As a result, it can be observed that in the segments smart environment, smart living and smart energy good results have been already achieved regarding the interaction of Smart Cities and Smart Buildings. On the one hand, this allows the development of a Smart City concept based on existing practical examples. On the other hand, this creates pressure to develop a similarly good approach in order to compete internationally. In addition, a lot of pioneering work needs to be done in the fields of smart mobility and smart data. This offers the opportunity to differentiate oneself from other competitors and to gain a competitive advantage through new concepts.

## 2.4 General Smart City framework 1.0

Based on the theoretical fundamentals regarding Smart City and Smart Building, a Smart City framework has been established in Figure 4. Most important are the people, the citizens, who play a key role in a Smart City as well as in the chosen methodological approach of human-centered design.

[115] cf. Apanaviviene et al. 2020, p. 15

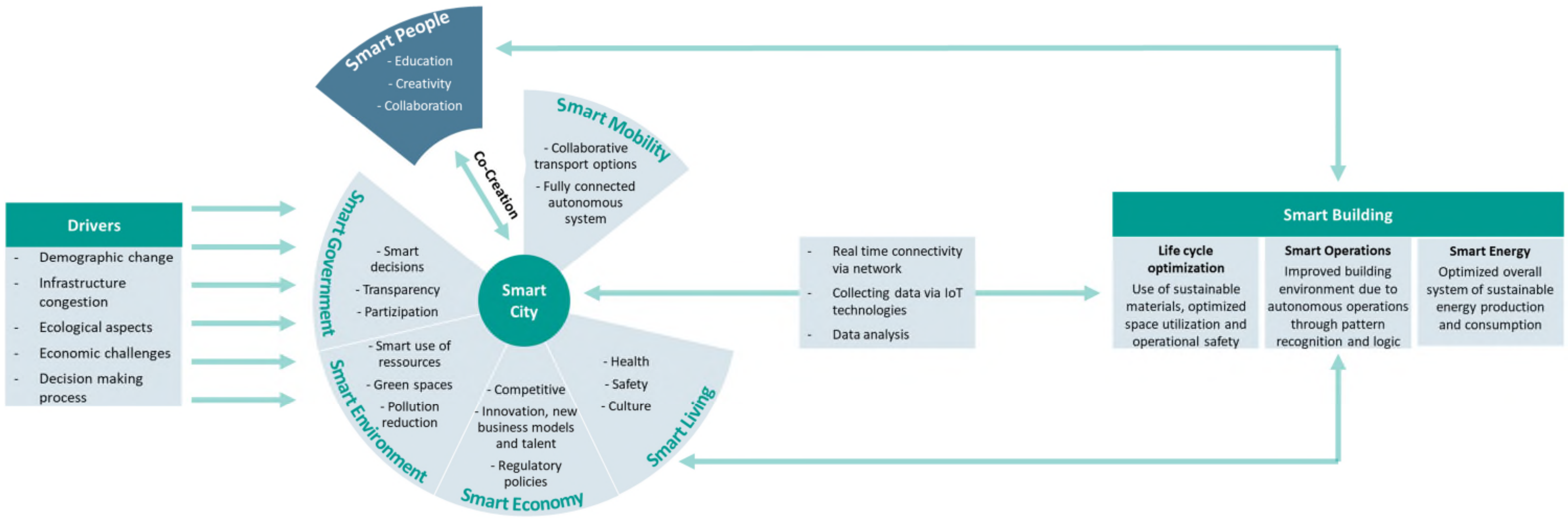


*Figure 4: General Smart City framework 1.0*

# 3 Definitions and relevant aspects relating the concept to be developed

As mentioned in Chapter 2, Smart Cities and Buildings enable simplifications in daily life. The core part of this is data collection and utilization as well as new approaches and ideas that allow an efficient use of a city. Different new technologies or concepts, that form the basis of the new design of a city are named in Chapter 2. Within this chapter, selected approaches and technologies, which are crucial for this thesis and the concept to be developed, are discussed. At first, the two terms IoT and (digitally) re-programmable space as a main part of this thesis are defined. In Section 2.3.2 data could be identified as a feature that distinguishes one from other Smart Cities. Furthermore, the use cases Songdo and Toronto in Chapter 2.1.5 indicated that privacy in the context of data sharing can be a major barrier for the success of Smart Cities. Therefore, the Part 3.3 describes the digital twin as a basis for data analysis and afterwards Section 3.4 discusses critical questions about the handling of data. Finally, solutions are mentioned for connecting people and the digital world, since this aspect is essential to ensure that Smart City operations are human focused.

## 3.1 (Digitally) re-programmable Space

In 2015, (digitally) re-programmable space ranks first among the Top 10 urban innovations of the WORLD ECONOMIC FORUM.[116] Three different aspects can be distinguished within the concept.

Firstly, the concept indicates that previously existing and underutilized infrastructure is being re-programmed in order to optimize its use. An example of such a project is Melbourne, where underused roads and other spaces have been redesigned into residential areas over the past 30 years.[117]

Secondly, the concept entails that spaces are designed within the planning in such a form that they can be reused or extended after a period of time without major structural changes, if the spaces are no longer needed for the originally planned purpose or are not sufficient for the actual development – the space becomes re-programmable over the life cycle. The building from Hauzenberg in Chapter 2.2.2 can be used as an example. HEIDARY considered in the planning phase, that floors are spatially, mechanically and electrically separable from each other and that the individual floors function autonomously with regard to smart home applications. If HEIDARY'S children move out of the home and less space is needed, floors can be rented to others and the owner only lives on a single floor. This not only optimizes the use of space but also generates economic benefits.[118]

[116] cf. World Economic Forum 2015, pp. 1, 4
[117] cf. World Economic Forum 2015, p. 4
[118] cf. Heidary 2020

The last aspect of this concept implies that buildings or spaces are (digitally) programmable in real time, which means that the space can change between various types of use or that the space is accessible to different users – the space is re-programmable in the daily routine. Therefore, the concept enables the multi-purpose usage of buildings and space or the utilization of available space is optimized.[119] This is relevant due to the fact that buildings are vacant for about 40% of their time, what creates a need for a mixed and optimized use of space, making buildings or space a part of a larger context.[120] Thereby smart digitally assistance systems can provide the necessary room for the user on basis of their needs and occupancy. An optimized space utilization without the help of digital system is conceivable as well. Since the room knows the requirements of the respective users and has the possibility to be accessible to different users and/or to adapt to different types of use through intelligent design or modern technologies, a perfect environment can be provided for the user. As a result, the use of available space is optimized and thus the number required space is reduced. The literature uses the extreme example that intelligent buildings can adapt their use immediately between a gymnasium, a theatre, a social center and a nightclub.[121] Realized examples are the building The Edge in Amsterdam or the 1111 Lincoln Road multi-storey car park in Miami. In The Edge, a flexible design and smart controls enables the only 1,100 workstations to be sufficient for 2,500 employees who should work in this building, which turns in optimizing the utilization of space.[122] The Car Park in Miami has an intelligent architecture that allows it to be used not only for its usual purposes but also for other activities such as sports courses or weddings.[123]

In Chapter 2.1.5 different approaches relating to (digitally) re-programmable space are already explained, for example allocating road lanes depending on traffic in Auckland, real time analysis for an optimal use of subways in Seoul and a bridge used for multi-purposes in Copenhagen. The key point of all concepts is to ensure that the available space is utilized optimally, whether for one purpose or for multi-purpose. Thereby, the concepts can focus on re-programmable approaches over the life cycle or within the daily routine.

In a Smart City, (digitally) re-programmable space is a key factor in social, environmental and economic terms. With the reuse of space or optimization of the space allocation, further investment in new buildings or necessary infrastructure can be avoided and, through optimized use, energy consumption can be improved, further sealed surfaces avoided and global resources protected. This in turn enables the optimization of the areas used for human life.[124]

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[119] cf. World Economic Forum 2015, p. 4; Schwab 2016, p. 79
[120] cf. Teubner, S. 2018
[121] cf. World Economic Forum 2015, p. 4; Schwab 2016, p. 79
[122] cf. World Economic Forum 2017, p. 15
[123] cf. World Economic Forum 2015, p. 4; Herzog & de Meuron 2010
[124] cf. Principles of Urban Sustainability 2016

## 3.2 Internet of Things

As mentioned in Chapter 2.1.4 and 2.2.1, IoT is identified as a main requirement for enabling Smart Cities and Buildings. The following chapter explains the terminology IoT, how IoT can be implemented and the comprehensive possibilities that this innovation entails. The following descriptions do not focus on the technical functions within the system but on the possibilities offered by IoT systems, as the concept to be established for MSP is supposed to indicate which IoT possibilities should be used and it is not part of this thesis to derive a fully functioning IoT network.

### 3.2.1 Definition

The Internet of Things describes technologies and applications which enable the connection and networking of physical intelligent components by using the internet.[125] This includes a fully-automated process that connects a variety of devices and allows them to exchange data in real time, what is essential for value creation in terms of efficiency and effectiveness.[126] The components (e.g. machines, home appliances) provide information about itself and their environment by using sensors and networking connectivity.[127] Through data analysis of these comprehensive information and the cooperation of the devices – especially sensors and actuators – an IoT system can automatically recognize certain scenarios and initiate reactions (mechanical, electrical or informational to humans).[128] This extensive process can be used for continuous improvement for instance in cities and buildings to optimize infrastructure and utilization of resources, thus increasing profitability, attractiveness and flexibility.[129] As a result, IoT will have an important impact on how we plan, design and operate future intelligent buildings.[130]

### 3.2.2 IoT system framework

An IoT system can be divided into different levels, each providing a specific function for the overall system. Figure 5 shows a conceptual framework of RAYES & SALAM, which illustrates how the components in an IoT system are related to each other.

[125] cf. Gassmann et al. 2018, p. 21; Deloitte 2016, p. 4
[126] cf. Bakker 2020a, p. 102; Deloitte 2016, p. 4; Rayes & Salam 2017, p. 2
[127] cf. Bakker 2020a, p. 102; Deloitte 2016, p. 4; Rayes & Salam 2017, p. 2
[128] cf. Bakker 2020a, p. 102
[129] cf. Deloitte 2016, p. 4; Deloitte 2015, p. 45
[130] cf. Bakker 2020a, p. 102

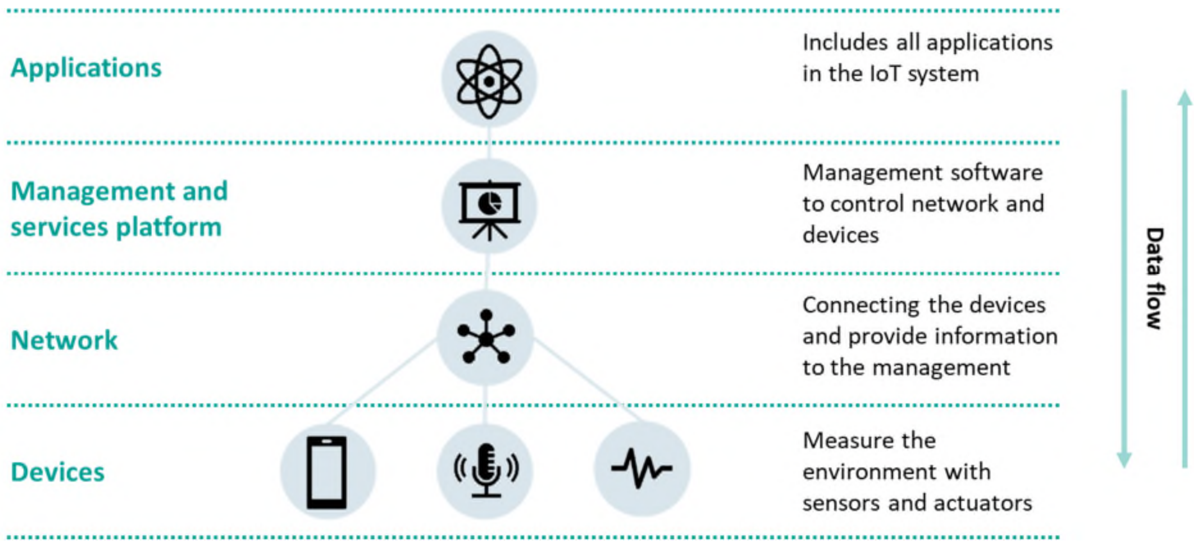



*Figure 5: Internet of Things levels*[131]

Since this chapter is intended to provide an overview of the possibilities how to use IoT applications, the following sections focus on the device level. This shows concretely how IoT can be applied in buildings or cities.

### 3.2.3 The things / devices

As mentioned in the previous section, IoT devices are intended to collect information about their environment in order to perform a specific action. The things in IoT, which mainly consist of sensors and actuators, are responsible for these functions. The devices, as the core of every IoT system, are described in the following and examples for their application are provided.

In an IoT system the sensor is used to measure physical parameters of changes in itself and its environment.[132] Within this measurement process the physical conditions of the real world are sensed as an analog input converted into a digital signal and provide an input for the digital IoT system.[133] In any IoT system, sensors are essential as they provide the link between the physical objects and the digital world. Consequently, the main purpose of sensors is to provide all necessary data about the environment for the entire system.[134] For the required performance, IoT sensors must provide some characteristics. Sensors should be able to filter the data to provide only the required information while minimizing energy consumption and noise. Each measurement should obtain information about objects without physical interaction and the sensors must be very sensitive to detect the slightest change in the environment.[135]

[131] own illustration based on Rayes & Salam 2017, pp. 2-3
[132] cf. Ejaz & Anpalagen 2019, p. 17; Alam et. al 2020, p. 9; Rayes & Salam 2017, p. 58
[133] cf. Milenkovic 2020, p. 28; Rayes & Salam 2017, p. 59
[134] cf. Rayes & Salam 2017, p. 59
[135] cf. Rayes & Salam 2017, pp. 64-65

There are different types of sensors for measuring environmental changes. According to RAYES & SALAM (2017), the following types are the most common ones:

- Temperature sensors
- Flow sensors
- Imaging sensors
- Air pollution sensors
- Infrared sensors
- Speed sensors[136]
- Pressure sensors
- Level sensors
- Noise sensors
- Proximity and displacement sensors
- Moisture and humidity sensors

The enumeration indicates that a variety of factors can be measured with the sensors, which enables a wide range of potential applications. In the following, various possibilities for the use of sensors in Smart Cities or Buildings are described (for a more comprehensive overview, see DELOITTE 2015, p. 45; the described examples are use cases for sensors, but do not work without data transmission and actuators):

- Energy consumption: Sensors can monitor the energy consumption of components within a smart grid or in a green building to derive further efficiency potentials
- Traffic: Speed sensors can be used to derive current traffic situations in order to provide the most suitable transport option for the user
- Lighting: Sensors can detect the motion of people and in conjunction with brightness sensors ensure the required lighting[137]

Beside sensors there is the possibility to collect information by Radio Frequency Identification (RFID) or video tracking. RFID is a mechanism for collecting information based on radio waves that are embedded in the so-called tag of an object. For example, the technology can be used for access control or logistics tracking. Video tracking is a process to extract information from a video. It can be used to measure the behavior or movements of objects or living beings.[138]

Within this chapter the possibilities of how an IoT system can sense by using devices were discussed. However, only the measurement of data is useless, since within the provided use cases of sensors, the sensors only measure the environment, but do not perform the desired reaction. The data must be analyzed and induce a reaction to control the environment in order to avoid unfavorable conditions.[139] To establish such reactions, actuators are used. Actuators receive control signals from a system to perform certain actions and thus use the information

[136] cf. Rayes & Salam 2017, pp. 60-64
[137] cf. Deloitte 2015, p. 45
[138] cf. Rayes & Salam 2017, pp. 67-69
[139] cf. Rayes & Salam 2017, p. 71

provided to influence the physical world.[140] According to RAYES & SALAM (2017), the following types of actuators are the most common ones:

- Electrical actuators
- Hydraulic actuators
- Manual actuators[141]
- Mechanical linear actuators
- Pneumatic actuators

As shown in this chapter, there are a variety of sensing and acting devices, which offer an enormous range of possibilities for the use in buildings or cities. Some applications have been shown already, but there are too many possibilities to list each application individually. However, all use cases or implementation ideas have an influence on the concept for MSP in Chapter 5.

## 3.3 Digital twin

Within a Smart City or Building, it is important that the overall system continues to evolve and adapt to its environment. To achieve this, all processes, products or services have to be digitally mapped within the digital twins, which are representations of physical and real objects of entire systems.[142] To accomplish this, digital twins have four main characteristics:

- Current status monitoring by sensors
- Analytical data structure
- Connectivity
- Visualization of the relevant data[143]

In this context, the digital twin is not only an illustration of the real situation and provides the data about the current condition, but it is also the basis for analytics solutions.[144] Through advanced data analysis and AI[145], this system independently recognizes patterns and improves the overall system in terms of ecological, economic and social aspects. Thereby it is important that the focus of digital decision making must be based on people and their environment.[146] In order to achieve such analytics solutions, the digital twin has to fulfil several requirements:

- Data accessibility: Includes data connections, standards applied and data governance
- Data structuring: Complexity of the digital twin has to be mapped in a structured way
- Scalability: Digital twin must be expandable and adaptable to new trends and developments

[140] cf. Alam et. al 2020, p. 9; cf. Rayes & Salam 2017, p. 71
[141] cf. Rayes & Salam 2017, p. 72
[142] cf. Deloitte 2017, p. 5; Gassmann et al. 2018, p. 20
[143] cf. Deloitte 2017, p. 5
[144] cf. Deloitte 2017, p. 5
[145] Artificial Intelligence (AI) describes the ability of a digital system to operate in a human-like manner, such as problem solving or decision making on the basis of machine learning (cf. Marr 2018). For this purpose, the system simulates a multitude of different scenarios, allowing the best decision making as well as learning from experience in simulation (cf. Bakker 2020a, p. 104).
[146] cf. Gassmann et al. 2018, p. 20

– Courtesy: Digital twin needs to be confidential (data security) and impartial[147]

Using extensive data, the digital twin visualizes and simulates different scenarios, making it a comprehensive way to plan, manage and control cities.[148] The interface between digital twin and real world is IoT, which uses sensors and actuators to collect the necessary information for continuous optimization.[149] IoT as a prerequisite for the Smart City is already examined in more detail in Chapter 3.2.

## 3.4 Privacy of data and data access

As mentioned in Part 2.3.2, smart data is one way to distinguish from other Smart Cities. However, this opens up potential for discussion regarding the privacy impact. Privacy barriers have already been demonstrated in the use cases of Songdo and Toronto (see Chapter 2.1.5), indicating that this aspect can be seen as a major risk. Therefore, some aspects relating to the handling of data during the development of a Smart Cities concept need to be considered. Regarding the data management in Smart City three different aspects exist: Privacy of data, data administration and data access. As these aspects have an impact on the overall concept of MSP, different variants are described in the following chapter.

### 3.4.1 Privacy of data

As mentioned in previous sections, within a Smart City, a variety of information is collected. Thereby data input uses different possibilities (e.g. sensors) to collect as much data as possible in order to improve operations and daily life by analyzing these data. The majority of this data is caused directly or indirectly by a human being. Therefore, during a Smart City development, it must be discussed the degree to which users have influence on the data they provide and thus give insight into their behavior. One possibility is to collect and process all data generated by a human being in a Smart City.[150] However, this could cause resistance, as it offers a detailed insight into the privacy of a user, which has a negative influence on the autonomy and online security of the inhabitants.[151] For example, this is demonstrated by the project in Songdo, where many avoid being completely networked although South Koreans can be described as technology affinities. This is shown by the current success of the project (see Chapter 2.1.5).[152] Therefore Decode, a project of the European Union, provides another possibility to influence data sharing. Thereby people are able to influence by themselves which data they want to share and for which purposes they can be used, thus controlling their own

[147] cf. Gassmann et al. 2018, p. 22
[148] cf. Gassmann et al. 2018, p. 21
[149] cf. Deloitte 2017, p. 5; Gassmann et al. 2018, p. 20
[150] cf. DW Shift 2019
[151] cf. Decode 2020a
[152] cf. Gassmann et al. 2018, p. 115

data. For instance, such an approach is used in Barcelona for an open democracy platform, which allows the inhabitants to participate safely in the governmental process.[153] In this context, it must also be considered that data is the most important asset in a Smart City. Without enough data, it is impossible for the city to learn on its own and thus constantly develop and optimize itself. Therefore, a concept such as Decode must ensure that enough data is available in the city. Otherwise the Smart City approach will become obsolete. However, with both approaches, it is important that all data is anonymized in order to ensure privacy and security of people.

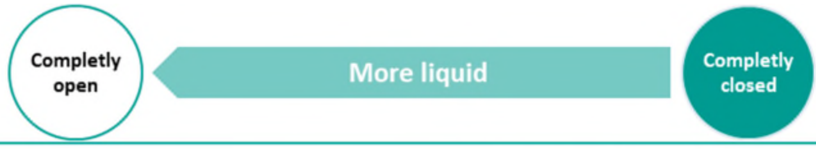
### 3.4.2 Data administration

In the context of data security, identifying the right data administrator is an essential issue. Thereby, the obvious solution is that the city administration manages and controls the data. From a privacy perspective, this is an effective solution, as administrations want to ensure the well-being and online-safety of citizens. However, many city administrations have problems to monitor, analyze and protect the data against unauthorized access, since their technical expertise is not sufficient. Therefore, the second approach, the management of data by large technology companies, is preferred in many projects. With their experience of several years they can offer a comprehensive solution which is secure, provides the needed capacity and meets today's technical standards for controlling masses of data. But in this case the issue arises whether the privacy can be guaranteed, because these companies use data of individuals for earning money. Clear policies and contracts need to be established, but best practices have still to be found. As a third approach, so-called data utilities are applied. These are organizations that are publicly-financed, but autonomous. This concept can combine the advantages of the other two approaches. However, on this issue no ideal solution exists, the approach must be specifically chosen on basis of the environment and technical expertise of the city.[154]

### 3.4.3 Data access

The last aspect in this chapter is the access to data. The question arises whether all institutions of a city should have access to the Smart City data or if there should be a differentiation for example regarding data sensitivity. In this context, the open and closed data approaches must be considered. Figure 6 compares both concepts.

[153] cf. Decode 2020b
[154] cf. DW Shift 2019




| | Completly open | Completly closed |
|---|---|---|
| **Degree of access** | Everyone has access | Access to data is to a subset of individuals or organizations |
| **Machine readability** | Available in formats that can be easily retrieved and processed by computers | Data in formats not easily retrieved and processed by computers |
| **Cost** | No cost to obtain | Offered only at a significant fee |
| **Rights** | Unlimited rights to re-use and redistribute data | Re-use, republishing or distribution of data is forbidden |

*Figure 6: Differentiation of open and closed data*[155]

As Figure 6 illustrates in detail, within the closed data approach, the collected data is only available to a limited extent for the different institutions. The data is often only available for individual monopolies who want to secure their position of power. Therefore, closed data approaches are often associated with political and competitive aspects. This leads to efficiency problems. For example, organizations or individuals seeking smart solutions for public benefit have no access to the required data, resulting in inefficiency, inequalities and loss of welfare.[156] That is why the open data approach is usually used in Smart City (e.g. Songdo City, Singapore, Vienna, etc.). Thereby, every individual and organization has access to all data, enabling them to create innovations. Furthermore, this concept allows to fully benefit from the added value of Big Data and thus to realize an enormous economic growth potential, to increase productivity and efficiency as well as to provide products and services that are needed by the population.[157] Since the data should always only be processed anonymously and as long as the data security, which was already mentioned in Chapter 3.4.2, is ensured, the open data approach poses no significant problems. As a result, it can be concluded that the open data approach is generally considered to be more promising, as full access to data enables the comprehensive innovative power of an economy to be used. However, different boundary conditions may lead to the closed data approach being pursued.

In summary, no universal best practice solution can be recommended for Chapter 3.4. Political conditions, legislation, traditions or even religions influence the concept in the respective city. Therefore, a location-specific approach has to be chosen and integrated in collaboration with the inhabitants.

[155] own illustration based on McKinsey Global Institute 2013, p. 3
[156] cf. Decode 2020b
[157] cf. McKinsey Global Institute 2013, p. 8-9

## 3.5 Connecting people and the digital world

As mentioned in Chapter 2.2.1, Smart Buildings can adapt their operations independently to their changing environment. However, it is essential to consider the human's individual desires and to connect the people to the Smart Building. There exist several possibilities to connect people with the digital world or even to move in it. These are described in the following sections.

Sensors provide a way for people to communicate with the digital world.[158] For example, lamps can only light up when a motion sensor detects that a person is in a room or a door only opens when face recognition software detects that the specific person has access to a certain area.[159] A more complex solution could be sensors that recognize a non-favorable environment on the basis of a facial expression. For example, if a light is too bright, this can be recognized by the emotions of the person and can be adjusted automatically.[160] However, sensors are rather an indirect way of communication, as humans do not active control what information is shared. More direct methods such as smartphones or digital assistants are discussed below.

In previously designed Smart Buildings (e.g. The Edge), the smartphone is a central component in establishing a collaboration between people and the digital world. For example, in an office building, employees can inform an app which type of workstation they need based on their appointments. The app then assigns a workstation to the employee for a specific day on basis of the user's requirements and occupancy. At the workstation, the employee can advise the app of his or her desired working conditions, such as lighting conditions, which will be automatically adjusted. Consequently, every employee has access to a perfect working environment.[161]

A more extensive connection between humans and the digital world are virtual assistants (e.g. Apple’s Siri or Amazon’s Alexa) based on voice assistance, which represents a more natural communication for humans.[162] Virtual assistants are human interfaces with social competence, which makes communication with the digital world more real.[163] In this context, the study by KHASHE ET AL. confirms that virtual assistants, which pose social dialogs, help to break barriers between the digital avatar and humans. This leads to the establishment of a relationship and therefore people interact better with the digital world. These more comprehensive information also contributes to an increase in building performance.[164] In addition, it is possible for users to interact with a virtual assistant not only in relation to building-specific information but also,

158 cf. Bakker 2020a, p. 101
159 cf. Deloitte 2018b, p. 9
160 cf. Bakker 2020a, p. 101
161 cf. Bakker 2020a, p. 118
162 cf. Bakker 2020a, p. 102; Bellingham 2019; Polakovic 2019
163 cf. Bakker 2020a, p. 102
164 cf. Khashe et al. 2019

for example, in terms of their to-do list or calendar, creating further connectivity for the digital world-human communication.[165] Another possibility digital assistants provide is that the virtual avatar can help people move through the building to find their workplace or to find a desired colleague who is needed.[166] As a result, digital assistants create the perfect working environment for people as well as simplify daily work and therefore a powerful method to increase employee performance.

These collaboration possibilities result in the situation, that the digital world observes us in our daily work and learns with every additional input. This enables the digital world to experience the requirements of each individual and thus anticipate the desired building atmosphere. Thereby the direct influence of the human being will decrease with every instruction to the system.[167] As a result, a highly efficient and productive environment is designed for people, creating new levels of engagement.[168]

A different approach than the methods mentioned above implies that people not only collaborate with the digital world but also dive into it and benefit from its extensive possibilities. Videoconferencing is already a widely used digital communication method. This is extended by virtual reality rooms (or augmented reality rooms), in which people are linked with the necessary information, the relevant work equipment and, if necessary, a digital assistant in a virtual room. This room offers extensive possibilities, which are practically impossible in the real world, and therefore forms an optimal business environment with extensive creativity and collaboration possibilities. In addition, space in buildings can be used much more flexibly and productively, since, for example, in office buildings a meeting room is not required for every single meeting.[169]

## 3.6 General Smart City framework 2.0

Based on the mentioned aspects within Chapter 3, the established Smart City framework from Chapter 2 could be extended and further specified. Figure 7 shows this framework. Further identified key aspects are in particular the digital twin, IoT and (digitally) re-programmable spaces.

[165] cf. Bellingham 2019
[166] cf. Bakker 2020a, p. 102
[167] cf. Bakker 2020a, p. 102
[168] cf. Deloitte 2018c, p. 5
[169] cf. Deloitte 2018c, p. 5

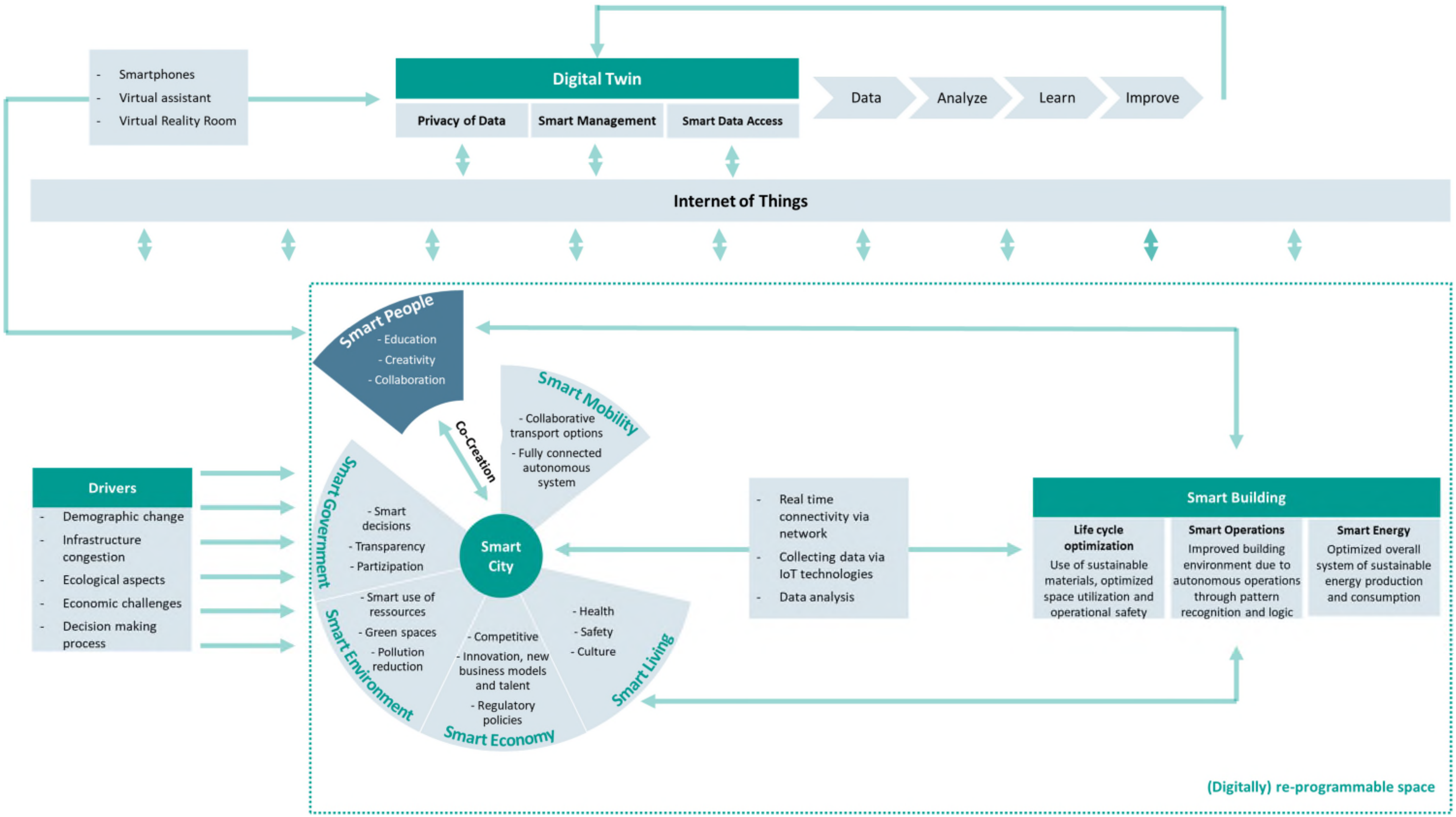



*Figure 7: General Smart City framework 2.0*

# 4 The project Maun Science Park

The concept to be developed must be aligned to the local boundary conditions. Therefore, the following chapter describes the country Botswana as well as the project MSP.

## 4.1 Botswana

The country Botswana lies in the southern part of Africa. It borders on South Africa, Namibia, Zambia and Zimbabwe. The country of Botswana and its inhabitants are affected by African and country-specific circumstances as well as have specific national characteristics which have to be considered in the concept. Boundary conditions regarding climate, energy etc. as well as the behavior of the people are discussed in the following section.

### 4.1.1 Boundary conditions

As a Southern African country, Botswana is associated with various African and country-specific influences. In the following, different boundary conditions, that influence the later concept, will be examined.

**Climate**

According to the MAUN WILDLIFE EDUCATIONAL PARK PLAN, the rainy season in Botswana is between November and December, whereby rainfall is irregular. By African conditions, winters are cold and dry, summers are semi-arid and autumn as well as spring are dry and warm.[170] A detailed overview of the average temperatures and rainfall over the annual course in Botswana is shown in Figure 8.

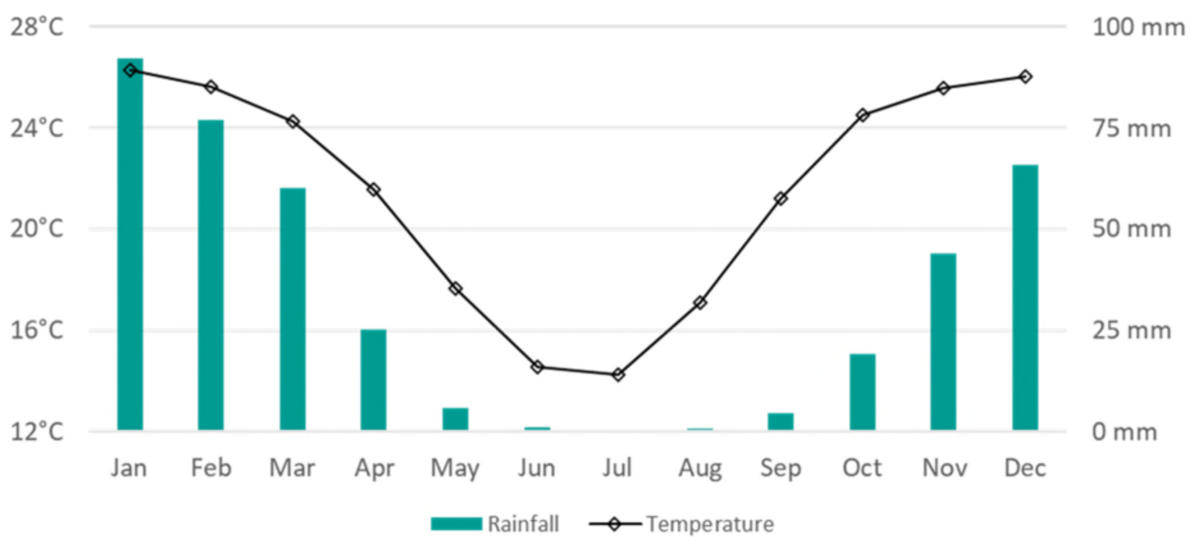



*Figure 8: Average monthly temperature and rainfall of Botswana for 1991-2016*[171]

[170] cf. Maun Wildlife Educational Park Plan
[171] own illustration based on The World Bank 2020a

Like all countries in the world, Botswana is also influenced by climate change. Precipitation continues to decrease and physical effects can already be seen in the Kalahari Desert, which is spreading further and further.[172] According to an analysis by the WORLD BANK, this effect is expected to intensify in the future years. Between 2040 and 2059 the analysis expects an additional temperature increase of 2.47 degrees and a further decrease in average rainfall of -63.92 mm per year within a high emission scenario.[173] The developments mentioned above are alarming, as they further complicate the challenges described in the further course of the thesis, for instance in terms of water and food supply.

**Energy**

In 2018 only 58.5% of the population of Botswana had access to electricity.[174] Compared to 100% access in economically strong regions (e.g. China, USA or Germany) and over 85% in emerging economies (e.g. South Africa or India), a clear deficit can be derived.[175] For the development of a Smart City, a power supply must be ensured, as this is a basic requirement for the functionality of state-of-the-art systems. This emphasizes the need for a development towards a comprehensive power supply.

In Botswana, over 50% of electricity is imported from South Africa and Zambia. 99.6% of the self-produced energy is generated from fossil fuel.[176] This shows that Botswana needs to create opportunities for self-produced renewable energy for its sustainable development and thus take the first step towards a successful economic future. The highest potential is offered here by solar energy with direct normal irradiation of 3,000 kwh/m$^2$/year; with average wind speeds of 4 m/s and, especially at the MSP, the low flow rate of the river, wind and water are no promising solutions.[177]

**Food**

In Botswana, as in most African countries, it is a major challenge to ensure the food for its inhabitants.[178] This fact is supported by various studies. Every year, the UN WORLD FOOD PROGRAMME publishes a world hunger map showing what proportion of the population is undernourished. In 2019, Botswana was ranked in the second worst category, which states that between 25.0% and 34.9% of the country's population is undernourished.[179] The study by the FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS also confirms a clear

[172] cf. Bühler 2020a
[173] cf. The World Bank 2020b
[174] cf. International Energy Agency 2018
[175] cf. Bühler 2020a; International Energy Agency 2018
[176] cf. United Nations Environment Programme 2016
[177] cf. United Nations Environment Programme 2016; Schallman 2020
[178] cf. Bühler 2020a
[179] cf. United Nations World Food Programme 2019

deficiency. It reveals that between 2016-2018 41.3% of the population of Botswana had to face strong food insecurity and 70.0% had to deal with at least moderate food insecurity.[180] Thus, there is a significant need to increase the security of supply by using new sources or by optimizing their own agriculture. The challenge of securing food for the population becomes further complicated by the steadily increasing population, which is discussed in Chapter 4.1.2.[181]

**Water**

Similar to the shortage of food, Botswana suffers from a lack of access to clean drinking water. According to the UNITED NATIONS World Water Development Report from 2019, about 20% of the population of Botswana had limited access to drinking water in 2015.[182] In the context of increasing climate change, the problem of water insecurity will continue to grow in the coming years. In the process, water is increasingly being seen as a cause of conflict or even war. This is confirmed by the water conflict chronology, which identifies 466 water-related conflicts worldwide between 2010-2019, compared to 220 between 2000 and 2009. In Botswana there is only one conflict like this known happened in the year 2002.[183] However, new ideas and methods must be developed in the future and also integrated into Botswana's cities to ensure access to clean drinking water and to counteract conflicts.

**Logistic**

To obtain information about a country's logistics capability, the WORLD BANK'S benchmark report Logistics Performance Index (LPI) can be used. In 2018, Botswana was ranked 58th in the LPI, which is a midfield position worldwide (167 countries in total) and an excellent position compared to other African countries (only South Africa is being ranked better at 29th place). However, the logistics capability is not comparable to countries in Europe, North America or China. There are delays, especially with highly developed technologies, as these are mostly imported.[184] Therefore, the concept to be developed must include systems that have predictive maintenance elements in order to procure spare parts at an early stage to prevent downtime.

**Waste**

According to a WORLD BANK study, waste management is a significant challenge in the Sub-Saharan African region, as the average total waste collection rate is only 44% (rate is significantly higher in urban areas than in rural areas).[185] This is due to the lack of clear guidelines, effective policy implementation and support as well as clear division of responsibilities.[186]

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[180] cf. Food and Agriculture Organization of the United Nations 2019, p. 124
[181] cf. Bühler 2020a
[182] cf. United Nations Educational, Scientific and Cultural Organization 2019, p. 143
[183] cf. Pacific Institute 2020
[184] cf. The World Bank 2018a, pp. 40-42
[185] cf. The World Bank 2018b; pp. 76-78
[186] cf. Mmereki 2018, p. 1

Furthermore, waste management in the municipalities can account for 30 to 50 % of the total annual budget.[187] At the same time, waste generation in the region is expected to triple by 2050 – currently the waste generation rate in Botswana is relatively low at 0.31 kg/capita/day.[188] This illustrates an enormous problem, since lack of waste management poses high risks, as it causes diseases, contaminates water resources or discourages tourists.[189] As a result, smart solutions have to be found to counteract the mismanagement of waste.

**Human-wildlife conflict**

Population growth, the development of prosperity and the expansion of agricultural activities are causing humans to expand their territories further and further into animal territories, resulting in decreasing living space for animals and resource competition between human and wildlife.[190] As a result, wild animals increasingly encounter humans, in some cases with significant consequences. Humans lose their crops, hence their food base, their property is destroyed and through direct contact with wild animals, humans suffer serious injuries. As retaliation or prevention measures the animals are killed, although numerous species are already threatened.[191] Since Botswana has a large number of animals (e.g. with 134,000 elephants the largest elephant population in Africa), a high number of human-wildlife conflicts occur – for example 4,843 crop conflicts and 14,933 livestock conflicts between 1994 and 2006 with elephants.[192] The interaction between climate change and further population growth may lead to a further increase in human-wildlife conflicts. Therefore, new concepts with the support of intelligent technologies are needed to enable the co-existence of humans and animals.

**Governance**

As an indicator for assessing governance within countries, the Corruption Perceptions Index (CPI), published by TRANSPARENCY INTERNATIONAL, which measures the degree of corruption in politics and administration, can be used as a benchmark.[193] With a CPI of 61 (value 0 indicates complete corruption; value 100 implies corruption-free), Botswana ranks second best in Africa and 34th worldwide. The country is comparable with the European countries Spain or Portugal (both CPI of 62).[194] Therefore, international organizations classify Botswana as a relatively less corrupt country. However, corruption still exists in Botswana at various levels of government. Therefore, new policies and approaches must be established to further reduce corruption and avoid an increase. Furthermore, Botswana can serve as best practice in Africa

[187] cf. Bühler 2020b
[188] cf. The World Bank 2018b; p. 76
[189] cf. Bühler 2020a
[190] cf. The World Bank 2016
[191] cf. World Wide Fund for Nature UK 2020
[192] cf. The World Bank 2016
[193]cf. Transparency International 2020a
[194] cf. Bühler 2020a; Transparency International 2020b

for democracy, rule of law, transparency and respect for human rights, which is both, a challenge as well as an opportunity.[195]

### 4.1.2 People

As identified in Chapter 2 and integrated into the frameworks, people are the key element of a Smart City. Therefore, the MSP concept has to be developed in accordance with the inhabitants of Botswana. In the previous chapter, challenges the population is facing in their daily life were already described. In this section, aspects about people living in Botswana will be discussed in more detail.

**Willingness for technological change**

The government in Botswana has initiated 4IR/Digital Transformation Strategy in order to evolve towards a knowledge-based economy. According to BOALOTSWE, a Maun resident, Botswanans support this trend and are willing for a change. Two reasons for this can be specifically identified with regard to the MSP. On the one hand, Botswanans are heavily dependent on the national water and electricity supply. Since the MSP enables solutions for self-sufficiency and provides simplifying aspects, it helps people to become more independent, especially within the supply of electricity and water. On the other hand, the MSP aims to offer practical solutions for people living in high human-wildlife conflict areas caused by the co-existence of elephants. Since these people no longer want to be confronted with recurring conflicts, they are willing to find new solutions based on technological change. As a result, Botswanans are ready for technological change, as it specifically aims to improve and simplify their life's as well as to provide a safer environment for them.[196]

**Daily routine in Botswana**

In order to develop approaches for (digitally) re-programmable space, the daily routine of Botswanans has to be taken into account. The following section differentiates between three groups – children, adults and retirees.

Children normally spend most of the day at school from Monday to Friday. Public school starts daily at 7:00 a.m., private schools at 7:30 a.m. Around 10 a.m. the children have breakfast break and at 1 p.m. lunch break. Before the lunch break, the children attend regular classes, whereby one class lasts between 30 and 40 minutes. After lunch, they stay at school, but they study on their own. Thereby they can choose any content which they have previously done in their lessons. This part lasts until about 3:30 p.m. Afterwards most of the students go to extra

[195] cf. Bühler 2020 a
[196] cf. Boalotswe 2020

activities like volleyball, basketball, table tennis etc. This part of the day takes place at the school as well. Between 5:00 and 6:00 p.m. the school ends and the children are picked up by their parents. As a result, the school must provide space for school lessons, breaks, group work and sports activities.[197]

Adults work from Monday to Friday. The working day starts at 7:30 a.m. for government officials and at 8:00 a.m. in the private sector. The normal working day ends between 3:30 and 5:00 p.m. Afterwards, parents – especially in the villages – pick up their children from school and spend the evening with them. Leisure activities and socializing with friends usually take place on weekends. Some groups of people, especially young people in cities, also meet in the evenings during the week as long as they do not have children. Retired people in villages spend most of their days on farms and take care of domestic animals. In the city retired people usually supervise small children.[198]

**Education**

With a literacy rate of 86.8% in 2013, more than 10% of the population of Botswana still had no sufficient education. However, significant improvements can already be identified. On the one hand, the literacy rate has risen by about 20% since 1990 (1990: 68.58%). On the other hand, the literacy rate for the 15-24-year old's is 97.5% and for the over 65-year old's it is 36.9%. This shows that the education system has improved enormously in the last decades.[199] Furthermore, Botswana has an above-average position in Africa, as many North African countries do not even reach the 50% mark for the 15-24-year old's (e.g. Southern Sudan, Chad, Niger).[200] Nevertheless, Botswana must overcome some challenges in the education system in the next few years. For example, only 43% of children between the ages of 4-5 have access to early learning opportunities and only 2/3 of the students pass the primary school exam.[201] Consequently, the education system must be further optimized and continuous learning opportunities created, especially for the older population. In addition, it will be important in the future to actively use the good education of people in a collaborative environment to generate innovations and gain economic advantages from them.[202]

**Demographics and urbanization**

In the last decade, the population of sub-Saharan Africa has risen from 869 million to 1.1 billion, an increase of 30.9% (an increase of 70.8% over the last two decades).[203] According to a study

[197] cf. Boalotswe 2020
[198] cf. Boalotswe 2020
[199] cf. UNESCO Institute of Statistics 2020a
[200] cf. UNESCO Institute of Statistics 2020b
[201] cf. UNICEF Botswana 2020
[202] cf. Bühler 2020a
[203] cf. The World Bank 2020c

by the UNITED NATIONS DEPARTMENT OF ECONOMIC AND SOCIAL AFFAIRS, the population is expected to further increase to 2.1 billion by 2050.[204] The growth in Botswana is to be classified lower due to the comparative birth rate (sub-Saharan Africa average: 4.7 births per woman; Botswana: 2.9 births per woman), but population growth will pose a challenge for Botswana as well.[205] Food supply has not been able to grow at the same rate in recent years, the need for housing and adequate infrastructure is rising and the increase in the young population brings benefits but also creates challenges. Therefore, new solutions have to be developed in the coming decades to face the challenges.[206] In addition, the trend of urbanization is evident in Botswana. Between 2000 and 2018, the proportion of urbanization has increased from approx. 54% to approx. 69%; the proportion of urbanization is estimated at 85% by 2050.[207] However, the trend in Botswana cannot be compared for example with Asian countries, where the Gross Domestic Product (GDP) per person rises with increasing urbanization, instead the GDP per person in Botswana falls with increasing urbanization. A key reason are informal urban districts such as slums. As a result, not only challenges for the expansion of the infrastructure arise, but completely new and more comprehensive concepts and approaches for urban infrastructure must be developed.[208]

**Health**

With an average life expectancy of 69.3 years, Botswana has a higher value than other countries in Southern Africa (e.g. South Africa: 63.8; Zimbabwe: 61.2; Namibia: 63.4). However, the value is below the global average (73.0) or the average in Northern Africa (e.g. Algeria: 76.7; Libya: 72.7; Egypt: 71.8).[209] In addition, Botswana has the highest HIV prevalence in the world at 23.0%, which leads to 28.7% of HIV deaths in 2017 originating from Botswana.[210] Other main causes of death are heart diseases, strokes and respiratory infections.[211] This shows that despite the high average life expectancy compared to other Southern African countries, Botswana needs to develop new approaches to counteract and treat diseases, especially HIV.

### 4.1.3 Existing design problems in African cities

According to a study by the WORLD BANK, three characteristics can be identified in African cities that currently handicap urban development and thus negatively affect the daily life of the inhabitants – crowded, disconnected and costly.[212] These are described below.

[204] cf. United Nations Department of Economic and Social 2019b, p. 6
[205] cf. The World Bank 2020d
[206] cf. Bühler 2020a
[207] cf. United Nations Department of Economic and Social Affairs 2018
[208] cf. Bühler 2020a
[209] cf. The World Bank 2019
[210] cf. Ritchie & Roser 2019
[211] cf. Centers for Disease Control and Prevention 2019
[212] cf. The World Bank 2017, p. 4

The central problem in African cities regarding crowding is that many people live in unplanned and informal neighborhoods. There is a lack of infrastructure, housing and the necessary capital investment within these parts of the cities. A key reason for such development is that cities are not economically efficient enough to sustain economies of scale, leading to unattractiveness for investments. This is due to the fact that parts of the cities are not densely and formally populated near the city center with immediate access to jobs, which results in a deficiency of an economically and commercially strong city center as well as access to services and work for the inhabitants. Informality is caused by the relative lack of cultivated space in the city center. For example, in Harare or Zimbabwe, 30% of the area within five kilometers of the city center is undeveloped, resulting in dysfunctional real estate markets and ineffective property use patterns. Consequently, the connection between undeveloped land within the city center, informal neighborhoods and the resulting unrealizable economies of scale creates a downward spiral, as economically weak regions tend to form further informal settlements.[213]

An obstacle to economic growth within African cities is the fact that many smaller neighborhoods within the urban structure cause spatial dispersion within the city. This leads to a lack of connection, which means that in contrast to other cities worldwide cities in Africa have lower exposure (residents are disconnected and cannot interact with each other) as well as higher fragmentation (population density within an area fluctuates significantly). The central reason for this trend is the scarcity of new development within the city center. Instead of concentrating capital and bundling new buildings, the boundaries of the cities are being pushed further outwards. The interaction of fragmentation and inadequate transport infrastructure results in costly and slow commuting, limiting the access to jobs in the urban area.[214] This leads to a separation of people including among themselves and businesses, which results in reduced economic opportunities.[215]

According to the WORLD BANK study, a 1% reduction in urban fragmentation leads to a reduction of 12% in urban costs. The fragmentation of cities in Africa results in economies of scale not being exploitable and high costs of living. Compared to countries with comparable income levels, city residents in Africa pay 35% more for food, 42% more for transportation and up to 31% more for services. Due to the higher cost of living and compensation payments for living conditions in informal settlements, firms have higher indirect costs as they have to pay higher wages. For example, unit labor costs in Djiboutiville (Djibouti) are three times higher than in

[213] cf. The World Bank 2017, pp. 10, 13
[214] cf. The World Bank 2017, p. 13
[215] cf. The World Bank 2017, pp. 13, 16

Mumbai (India). As a result, cities in Africa are often avoided by investors since high costs limit their efficiency and therefore their competitiveness.[216]

In summary, current urban design in Africa is causing higher operation costs for households and businesses through informality and fragmentation. As a result, efficiency and competitiveness within cities is limited and thus these facts obstruct a successful economic, social and ecological future.

## 4.2 Maun Science Park

This thesis focuses specifically on a concept designed for the MSP project. The main objective of MSP is to provide best practice for future infrastructure development by creating a Smart City within the park as part of the transformation strategy of Botswana. In the following, the project, its vision and elements will be explained as well as the area of MSP will be introduced.

### 4.2.1 Location

Maun lies in the north of Botswana. The city is located next to the Moremi Game Reserve. This nature reserve is part of the Okavango Delta, one of the last large wetlands in the world. As such, all the water in this area evaporates and does not flow into a lake or sea.[217] Figure 9 shows the location of the MSP and the shape of the property.

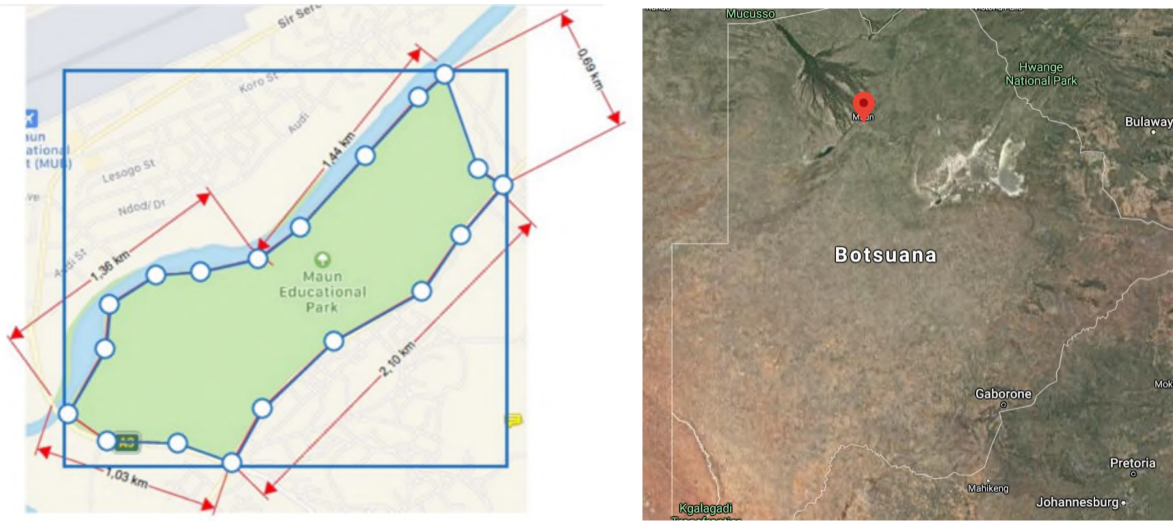


*Figure 9: The site of Maun Science Park and location of Maun in Botswana*[218]

MSP is located south of Maun Airport and adjacent to the Thamalakane River (see Figure 9). The property of the park is limited to an area of 250 ha, with a maximum length of 2.8 km and

[216] cf. The World Bank 2017, pp. 17-19
[217] cf. Bühler et al. 2020b
[218] Bühler et al. 2020b

width of 1.2 km. This area is to be partly developed and partly preserved as a smart nature reserve. The property has two different appearances over the annual rhythm. During the rainy season it is green, during the dry season the area is characterized by a high dryness.[219]

### 4.2.2 Vision

The vision of the project is to support the transformation of Botswana from a mining-oriented industry towards a knowledge-based society within the 4IR/Digital Transformation Strategy. A futuristic and self-sufficient (e.g. in terms of electricity or water supply) urban plan should be developed, which is scalable through its modularity. Thereby it shall serve as a living experiment to test the feasibility of smart solutions in an African city and to form a learning base to adapt the approach to other contexts in Botswana or Africa. Therefore, local (e.g. human-wildlife conflict, water and food shortage) and global (e.g. climate and demographic change) challenges should be managed, technologies should be used to protect the environment and thus create a beneficial interaction between a city and its environment as well as lifelong education and health for its inhabitants should be ensured.[220] As a result MSP "will have an economic and social impact for local and regional communities and industry by creating jobs, reviving local supply chains and creating novel markets that address the regional challenges through the application of proven technology"[221].

### 4.2.3 Goals

According to KOULOLIAS, key initiator of the project, the main target of MSP is "to build, study and understand a test habitat within an unlimited ubiquitous, connected and aware system in which machines, humans and applications interact to enrich our daily life"[222]. The intention is to create a sustainable, self-sufficient and Smart City that focuses on human beings and creates future-proof economic and administrative models.[223] In this context, five specific sub-goals can be derived:

- Made for and by Botswana: The design and functionality of the city aims to meet the specific requirements of local stakeholders as well as to be realized through local resources
- Creation of highly modern living environment: Designing an infrastructure including a Living Lab that counteracts local challenges and integrates them beneficially into its ecological environment by using highly intelligent communication systems

[219] cf. Bühler et al. 2020b
[220] cf. Bühler et al. 2020b
[221] Bühler 2020c
[222] Koulolias 2020
[223] cf. Bühler 2020c

- Development of a knowledge base: Forming approaches for a sustainable community in Botswana and Africa through living learning projects and the integration of knowledge institutions
- Reference example for Innovations Regulation: Developing a best practice model on how governments deal with the integration of technologies into cities and its environment
- Creation of jobs and securing prosperity: Establishing a Smart Living Business Incubator, which provides a collaborative environment that fosters innovation[224]

### 4.2.4 Required smart solutions

In Chapter 4.1, various factors influencing the MSP are described. From these, various areas can be identified which require intelligent solutions as part of the concept to be developed. According to BÜHLER ET AL., the main required solutions can be classified into the following core elements:

- Energy: Sustainable energy production and optimized energy use
- Construction: Use of sustainable and local resources
- Water/Sanitation: Ensuring access to drinking water and recycling of wastewater
- Waste management: Minimization of waste and ensuring recycling
- Transportation/supply: Ensuring multi-modal transport model and supply routes
- Digital connectivity: Developing best practice and creating added value through networking
- Food production/agriculture: Securing a self-sufficient food supply under the given conditions
- Healthcare: Prevention of diseases and ensuring quality health care
- Education: Ensuring lifelong learning and developing knowledge economy
- Governance: Creating an innovation-enhancing environment and transparency
- Social cohesion: Holistic approach that focuses on humans and promotes collaboration[225]

The areas mentioned above are used as a reference basis, but are not exhaustive. Therefore, they will be expanded and classified within Chapter 5.

[224] cf. Bühler 2020c
[225] cf. Bühler et al. 2020b

### 4.2.5 Elements of the concept

Based on the visions, goals and boundary conditions, individual components can be identified which should be implemented within the project MSP. Figure 10 shows the operational framework, which lists the elements of the concept and various research areas.

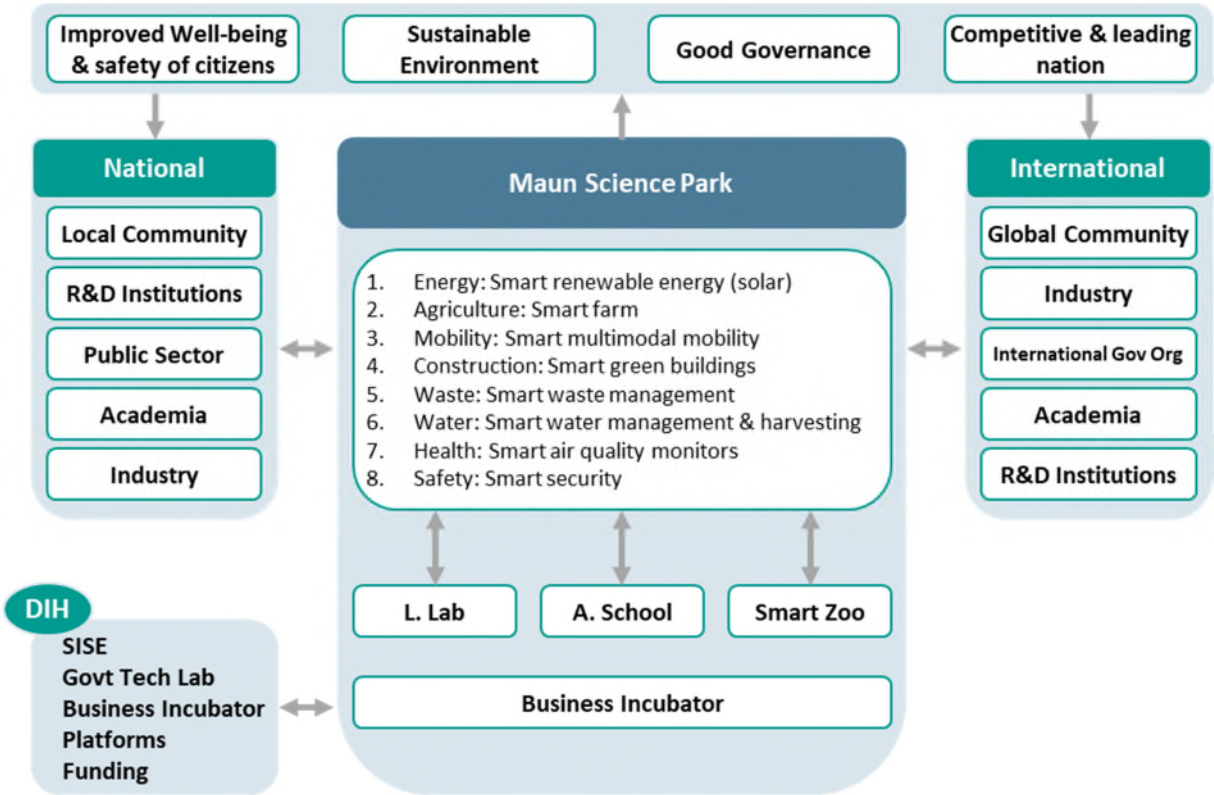


*Figure 10: Operational framework of Maun Science Park*[226]

Based on Figure 10, four functional centers can be derived – Maun Living Lab for Smart Habitats ("L.Lab"), Africa School of Design and Engineering ("A.School"), Smart Zoo ("Smart.Zoo") and Smart Living Business Incubator ("SmartIncubator"). In the following, the contents of these elements are briefly described.

**L.Lab:** A Smart Village with a total of 25 smart homes is to be implemented within the project. According to the Smart Building concept, the buildings will be designed sustainably as well as equipped with digital solutions that offer an optimized living environment based on regional requirements. Through modular construction, the smart home concepts should be transferable and therefore scalable for Botswana and Africa in order to serve as best practice. The objective of the Smart Homes within the Living Lab is to improve the quality of life and efficiency within

[226] own illustration based on Bühler 2020d

the community as well as to meet the needs of stakeholders in terms of social, environmental and economic aspects while minimizing the impact on the built environment.[227]

**A.School:** In cooperation with national and international universities and firms, the leading African School in Design and Engineering is to be established in MSP, focusing on applied science and the technologies within the project. Within the school, the 100 most technologically skilled students and 75 apprentices from Botswana will be trained in innovation and business start-up skills through workshops, lectures and projects. In this way, the school concept will serve as a basis for school reforms by providing best practice approaches to design and engineering education.[228]

**Smart.Zoo:** Within the MSP a protected area for endangered animals including a hospital for injured animals will be created. By using intelligent technologies, the human-wildlife conflict will be counteracted and the safety of the animals secured. The acquired data within an open data approach will be provided to national and international researchers and thus serve as a basis for the behavioral research of animals in order to further optimize the coexistence of humans and animals.[229]

**SmartIncubator:** In addition to educational support and the provision of an optimal working environment within the Living Lab, business start-ups are to be supported by Business Incubator. They will be promoted regarding financing, administration and consulting services in order to generate new solutions for intelligent living, to provide jobs and to commercialize the established business models. Consequently, the Business Incubator is intended to serve as a basis for the creation of intelligent infrastructures and the development of competitive companies in Botswana.[230]

Other areas to be integrated into the MSP are a transport system, a community center, a health clinic, facilities for entertainment as well as meeting rooms, for example for the village council.[231] Furthermore, intelligent solutions for energy supply, agriculture, construction, water management, waste management and security are to be developed and integrated into the MSP concept (see Figure 10 and Chapter 4.2.4).[232] Key factors for the development of both, the four functional centers as well as the additional elements, are scalability and best practice transferability to Botswana and Africa.

[227] cf. Bühler 2020d
[228] cf. Bühler 2020d
[229] cf. Bühler 2020d
[230] cf. Bühler 2020d
[231] cf. Bühler et al. 2020b
[232] cf. Bühler 2020d

## 4.3 Smart City framework Maun Science Park

Through the elaboration of Botswana's boundary conditions and challenges as well as through the specification of the MSP project, the Smart City framework developed in Chapters 2 and 3 could be adapted to the specific requirements of the MSP. Figure 11 shows the MSP Smart City framework. It should be emphasized that as a result of the input in Chapter 4 the drivers are extended and project requirements are integrated. Based on these findings, the segments of the Smart City are expanded by Smart Farming, Smart Water and Smart Energy, as these areas are both, major challenges in Botswana as well as areas for which intelligent solutions are required in the project definitions. Therefore, these areas should be seen as main segments and not as sub-categories. The segments are expanded by the Smart Data segment as well. One reason is the fact that this sector is a segment in which Botswana or the MSP can distinguish itself from other projects, as this area is not well developed yet (see Chapter 2.3.2). Furthermore, the handling of data is identified as a main reason for the failure of projects (see use cases Songdo and Toronto in Chapter 2.1.5). However, balancing between data availability and privacy is important, as the digital twin depends on data in order to optimize city operations. As a result, the area Smart Data has to be taken as a priority by placing it into another main segment.

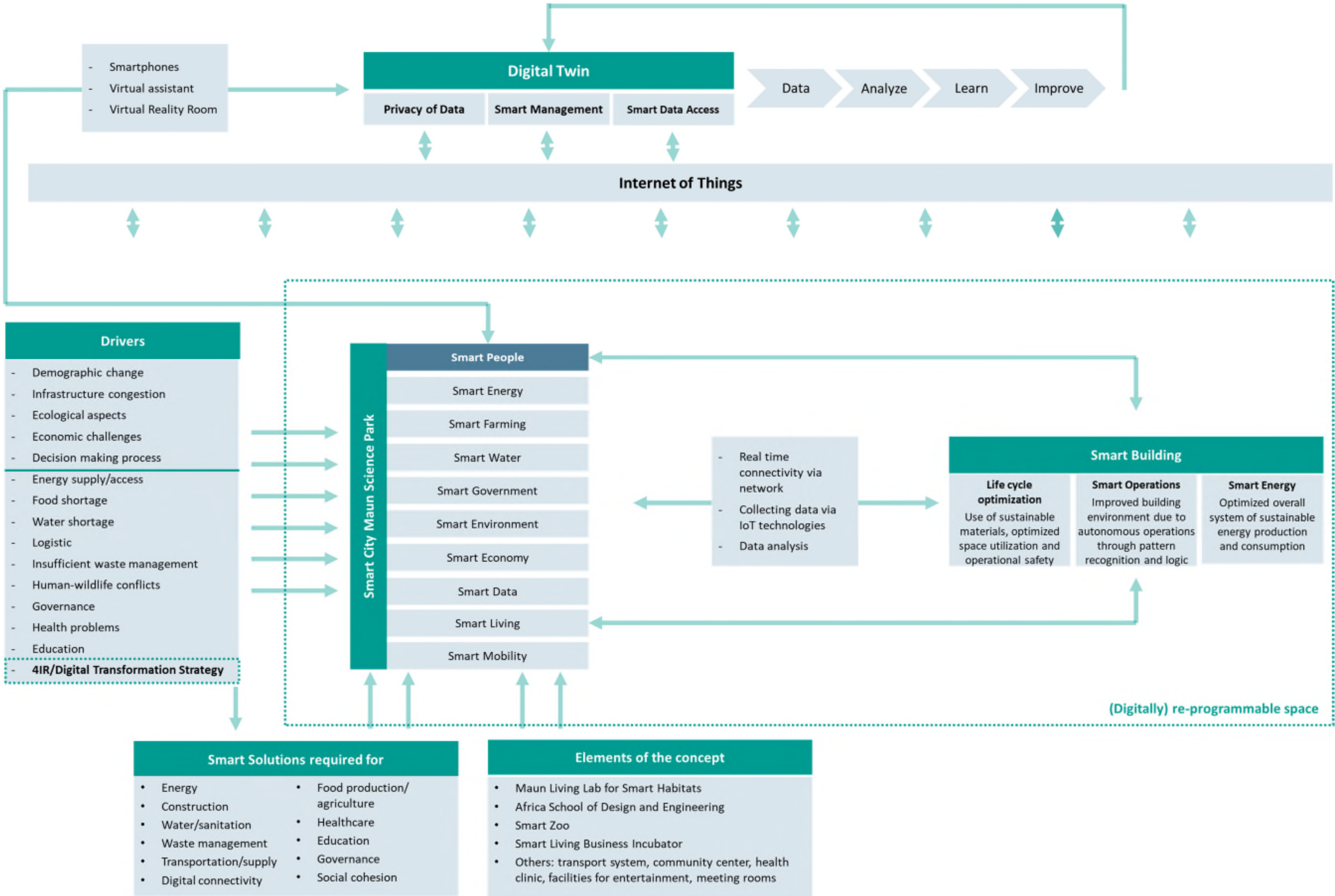


*Figure 11: Smart City framework Maun Science Park*

# 5 Concept Maun Science Park

Within the Chapters 2 to 4 the first part of the human-centered design – the inspiration phase – was examined and the range of information was continuously directed towards a specific concept for the MSP. Within this section, the ideation phase of the human-centered design will first establish the synthesis concept and then develop approaches for the (digitally) re-programmable spaces, thus targeting the information funnel to a specific element. Afterwards, for a critical examination the added value and the business model are verified based on various analyses. This forms the basis for Chapter 6 – especially for the recommended actions.

## 5.1 Methodology of concept development

As already mentioned, this chapter forms the ideation phase of human-centered design. Thereby, it is important that the focus is always on added value and requirements of the people. Firstly, the synthesis concept was developed in Chapter 5.2. This consists of the comprehensive definitions of solution areas for MSP, but also for Smart Buildings, as buildings were identified in Chapter 2.3 as key elements for the success of a Smart City. Based on the MSP framework (see Figure 11), local requirements and challenges as well as the comprehensive literature research, solution areas for the city were first identified and divided into further sub-segments. Secondly, these sub-subsegments were defined and requirements for each area were outlined (see Table 2). In the process, the methodology of human-centered design was applied through iteration phases. This means, that the concept was developed, subsequently compared with requirements and challenges and afterwards further developed (see Appendix 7). Additionally, feedback of the supervising professor BÜHLER was received on the basis of a summary presentation (see Appendix 5). Therefore, the process ensured that the concept is innovated according to the requirements of the locals. Afterwards, relationships between the segments of the city were displayed within a matrix in order to identify key intersection areas (see Figure 12). Finally, a qualitative assessment (see Figure 13) of the impact and economic affordability of the city segments enabled a prioritization. The result is based on the discussion between the author and the expert HERO. As a second part of the synthesis concept, the solution areas for the Smart Buildings (see Table 3) were defined in Chapter 5.2.2. The approach was similar to the one used to develop the areas for the city. However, in the interaction matrix, the connections between city and building segments were shown. BAKKER served as expert for the prioritization of the building segments. As a conclusion of the synthesis concept, in Chapter 5.2.3 sub-segments that are essential for the success of the Smart City are discussed based on the interaction matrices (see Figure 12 and Figure 14) and the expert input of HERO.

As second part of this chapter, approaches for (digitally) re-programmable space were developed. For this purpose, information regarding project requirements (see Chapter 4.2), the habits and requirements of the local population (see Chapter 4.1) as well as already applied approaches from Chapter 2 and 3.1 were combined to develop a variety of solutions. In order to develop based on an iterative process and people focused, a feedback round with the supervising professor BÜHLER was completed before the elaboration of the concepts (see Appendix 6). Afterwards, the requirements were defined and any IoT solutions that might be required were derived on the basis of the theoretical input in Chapter 3.2 and the requirements.

As a final point of this chapter, for a critical examination and as basis for the implementation phase of human-centered design, the developed concepts were considered as a whole in Chapter 5.4 – synthesis concept combined with approaches of (digitally) re-programmable space. Thereby the total added values were summarized at first. Afterwards, the strengths, weaknesses, opportunities and threats of the concept were identified in a SWOT analysis. Finally, the business model was examined by classifying the concept in the Business Model Canvas. These critical analyses in combination with the prioritizations within Chapter 5.2 form the basis for the recommended actions in Chapter 6, which is defined as the implementation phase within the human-centered design.

## 5.2 Synthesis concept Maun Science Park

A main goal of the thesis is the development of a synthesis concept for the MSP. This will be formed by identifying different solution areas for both, Smart City and Smart Buildings. In the following chapter these segments as well as requirements for them are defined, direct points of interaction are presented, prioritizations are derived and key areas are highlighted.

### 5.2.1 Maun Science Park segments

The first part of the synthesis concept is the approach for the Smart City MSP. In this section the defined areas are described and analyzed in detail.

**Description and requirements of the segments**

Based on the Botswana-specific requirements and challenges, the project requirements as well as the general Smart City approach, ten core elements of the MSP have already been derived within Figure 11. These elements were further detailed by using the methodology explained in Chapter 5.1, resulting in a total of 37 sub-segments. In their entirety these sub-segments form the synthesis concept of the MSP. Each of the areas is defined in Table 2 as well as requirements for each area are determined based on the different input conditions. Through extensive research, a comprehensive development process and based on the requirements, direct interfaces between the sub-areas have been identified as well. These interfaces are shown in Figure 12, illustrating the entire interconnection of the city.

| Segment | Sub-Segment | Description | Requirements |
|---|---|---|---|
| Smart Energy | Smart Production | Ensuring a renewable energy supply for the MSP at all times | - Sustainable energy production appropriate to the location by using renewable energies (self-sufficient if possible)<br>- Construction according to the boundary conditions (e.g. alignment)<br>- Use of a durable, sustainable technology that is appropriate to the boundary conditions<br>- Detailed planning for optimized dimensioning of energy production plants<br>- Intelligent allocation of the plants to minimize the environmental impact (e.g. on buildings)<br>- Interaction between central and decentralized systems |
| | Smart Grid | Intelligent energy network that optimizes the interface between production, storage and consumption, thus enabling a self-sufficient system | - Creating the interface by networking and balancing the input/output variables of production, storage and consumption<br>- Monitoring of the entire system and derivation of optimization measures within the digital twin<br>- Use of a self-thinking system based on AI that optimizes the overall system at any time<br>- Real-time transparency towards stakeholders to enable optimizing impact and economic opportunities |
| | Smart Storage | Application of a sustainable storage system as a balancing variable within the smart grid that ensures a continuous energy supply | - Connection to production and consumption within the smart grid to compensate for fluctuations within the system<br>- Sufficient dimensioning of the storage capacities to ensure a continuous energy supply in peak times<br>- Use of a sustainable, durable energy storage technology that meets the requirements of the framework<br>- Ensure continuous maintenance of the system to maximize the lifetime and capacity of the technology |
| | Smart Consumption | Implementation of energy-efficient and smart consumption systems and components to minimize the total energy demand of the city | - Use of energy-saving components<br>- Use of intelligent technologies to minimize the switch-on time of the component<br>- Formation of a total consumption system that provides the energy where it is actually needed through interaction<br>- Educating people about efficient energy consumption |

| Segment | Sub-Segment | Description | Requirements |
|---|---|---|---|
| Smart Farming | Smart Irrigation | Intelligent and efficient irrigation in agriculture | - Intelligent and water-saving irrigation based on the interaction between soil moisture and weather data<br>- Autonomously functioning irrigation system<br>- Utilization of water that has been sustainably gained according to its use |
| | Smart Harvesting Security | Securing the harvest from environmental influences | - Securing the harvest from wild animals<br>- Targeted, sustainable use of fertilizer and pest control<br>- Ensuring the necessary irrigation<br>- Protection possibilities against strong environmental influences (e.g. extreme heat, heavy rain) |
| | Smart Automation | Increasing efficiency by automation technologies for time and cost optimized agricultural processes | - Simplification and optimization of the agricultural process in terms of efficiency and economic aspects<br>- Use of technologies appropriate to the location<br>- Use of suitable automation technologies within various agricultural processes<br>- Ensuring automation and consequently harvesting through maintenance |
| Smart Water | Smart Collection | Implementation of a multidimensional water supply system to ensure the water availability for the city at all times | - Use of multidimensional water extraction systems (use of different water sources) to ensure supply at all times<br>- Supply as self-sufficient as possible<br>- Differentiation in water extraction from use-specific qualities<br>- Detailed planning for optimized dimensioning of the systems<br>- Use of construction methods and sources of supply corresponding to the location<br>- Intelligent design and space utilization of the plants to minimize the environmental impact<br>- Interaction between central and decentralized systems |
| | Smart Conservation | Integration of quality-preserving water storage systems | - Sufficient dimensioning of storage capacities to ensure a continuous water supply in peak times or in very dry seasons<br>- Use of quality assurance systems<br>- Integration of water treatment options<br>- Dimensioning for balancing the fluctuations of Smart Collection and Smart Consumption |

| Segment | Sub-Segment | Description | Requirements |
|---|---|---|---|
| Smart Water | Smart Consumption | Implementation of water-efficient consumption systems and components as well as use-specific water quality dimensions in order to minimize the total water demand and optimize the water utilization of the city | - Training of people regarding the use of water<br>- Implementation of types of use where different water qualities can be applied in order to avoid always having to provide drinking water quality<br>- Use of low consumption systems<br>- Overall consumption monitoring to derive optimization measures and to increase people's awareness of their consumption<br>- Optimize use of water capacity for irrigation |
| | Smart Recycling | Integration of water recycling systems for the reuse of wastewater in order to establish a closed water system | - Recycling of waste water to create a closed water cycle and thus minimize required additional water input from external<br>- Introduction of different treatment qualities, since not every type of use requires drinking water quality<br>- Use of high-quality water treatment plants to provide drinking water that is not hazardous to health<br>- Combination between central (e.g. sewage treatment plant) and decentralized (e.g. systems in houses) systems |
| Smart People | Smart Education | Providing learning opportunities for different interest groups to build up a knowledge base and establish the fundamentals of a highly efficient co-creation network | - Africa School of Design and Engineering as best practice for education and promotion of talents<br>- Basic education of people with regard to economic, social and ecological aspects as well as digitization technologies to ensure a sustainable, healthy and successful future<br>- Educational and promotional programs for people of different ages, development and knowledge levels<br>- Basic training for co-creation network<br>- Life-long learning through digital learning programs |
| | Smart Collaboration | Creation of an intelligent and collaborative exchange of people within the city and externally to form a collective community | - Creation of collaboration network and collective community respecting the traditional Kgotla<br>- Provide the necessary collaboration tools and technologies<br>- Ensuring an exchange within and outside the city<br>- Provision of required knowledge for effective collaboration<br>- Initiatives to promote collaboration |

| Segment | Sub-Segment | Description | Requirements |
|---|---|---|---|
| Smart People | Smart Privacy (human-based) | Securing the privacy and autonomy of people while maximizing data availability by creating a knowledge base about data services | - Initiatives to educate people about the need for data within a Smart City (as a basis for optimization within the digital twin and to ensure the functionality of the Smart City) as well as how to handle their own data<br>- Consulting and decision support regarding the provision of data and the protection of one's own digital privacy<br>- Initiatives to increase awareness of data handling |
| Smart Government | Smart Decision | Optimized decision making within the city based on collective intelligence | - Creating collective intelligence through the use of digitalization technologies and collaboration<br>- Optimized decision-making and handling of social, ecological and economic problems based on collective intelligence and by respecting the traditional Kgotla<br>- Development of approaches that enable participation of individuals as well as collaborative decision making<br>- Initiatives to encourage proactive participation<br>- Support of decision making through well founded and fact-based data analysis<br>- Educating people about participation in the decision-making process in order to enable people of all social classes to participate (equality) |
| | Smart Policies | Elaboration of innovation and business promoting policies to enable the operation and further advancement of the Smart City | - Development of guidelines that promote the daily operation and further development of the Smart City in all segments<br>- Focus on policies that encourage innovation and the introduction of new business models<br>- Policies must ensure the city's competitiveness<br>- Guidelines should be attractive for companies and talents |
| | Smart Transparency | Attaining complete transparency of decision-making within the city to ensure acceptance | - Development of approaches and concepts that create transparency in all Smart City segments and decision-making phases<br>- Use of information tools that are accessible to people of all social classes<br>- Initiatives for promoting transparency to prevent corruption |

| Segment | Sub-Segment | Description | Requirements |
|---|---|---|---|
| Smart Environment | Smart Waste | Providing a sustainable closed material cycle based on reusable materials | - Educate people regarding waste avoidance and separation<br>- Use of recyclable materials<br>- Use of intelligent solutions for waste collection<br>- Recycling of waste enables the reuse of materials |
| | Smart Human-Wildlife | Enabling the co-existence of humans and animals by applying intelligent technologies to achieve a beneficial interaction between the built city and its environment | - Early detection of potential human-wildlife conflicts<br>- Clear separation of people and wildlife through a well-founded urban structure<br>- Monitoring of animal behavior and enabling co-existence of humans and animals through data analysis (e.g. for tourism) |
| | Smart Resources | Providing a supply of resources appropriate to the city location and creating a closed resource cycle by implementing approaches for reutilization and usage of reusable resources | - Use of local resources appropriate to the location<br>- Intelligent resource allocation<br>- Recycling of waste and use of reusable materials<br>- Sustainable production and use of energy<br>- Self-sufficient, sustainable production of food<br>- Sustainable extraction and reuse of water<br>- Monitoring of resource consumption (or resource cycles) to derive optimization potentials and to raise awareness<br>- Use of predictive maintenance systems to procure required resources in advance |
| | Smart Space Management | Optimizing space utilization over the life cycle and providing a well-organized urban structure, while maximizing the area of environmentally friendly green spaces | - Integration of green spaces into the urban structure<br>- Creation of a well-organized urban structure (connection instead of fragmentation)<br>- Optimal space utilization and minimization of sealed areas<br>- Integration of multi-purpose usage possibilities<br>- Consider conversion/expansion possibilities in the design<br>→ Integration of approaches for (digitally) re-programmable space (see Chapter 5.3) |
| | Smart Pollution Management | Minimization of negative emissions for the environment and humans by creating a climate-neutral emissions concept | - Use of climate-neutral, low-emission and renewable energy<br>- Use of sustainable and emission-minimizing (with regard to exhaust and noise) traffic concepts<br>- Preventive detection of health risks within the air<br>- Avoidance of fossil fuels for energy supply |

| Segment | Sub-Segment | Description | Requirements |
|---|---|---|---|
| Smart Living | Smart Building | Integration of self-thinking buildings that interact with the urban concept to optimize space utilization, operations in the city and the use of all resources over the life cycle | see Smart Building segments in Table 3 |
| | Smart Health | Ensuring the health of people living in the city and creating an environment conducive to health | - Establishment of a hospital<br>- Educating people about healthy lifestyles and communicable diseases (e.g. HIV)<br>- Predictive detection of health risks within health data by using data analysis technologies (especially AI)<br>- Preventive detection of health risks within the environment (e.g. pollution) |
| | Smart Safety | Protection of people against any hazardous impacts | - Protection of people and their property from wild animals<br>- Measures concerning health<br>- Comprehensive concept for protection against crime<br>- Integration of approaches to identify and solve grievances within the city<br>- Building structure suitable for environmental influences in order to protect against extreme climatic conditions<br>- Approaches to secure the privacy and autonomy of people within data technologies<br>- Predictive systems should recognize potential risks in advance through data analysis (especially AI) |
| Smart Economy | Co-Creation network | Development of interactive value-adding processes by individuals and companies within a co-creation network through the use of collective intelligence based on collaboration | - Providing collaboration networks in which collective innovations are enabled<br>- Providing a network that can be used by people from all social classes<br>- Initiatives to promote participation within the network<br>- Education of the people regarding the necessary know-how to participate in the innovation process<br>- Provide regulations that allow the necessary decision making and innovation processes |

| Segment | Sub-Segment | Description | Requirements |
|---|---|---|---|
| Smart Economy | Innovation Lab | Providing a creative, collaborative and innovation-promoting environment within an innovation lab for generating new business ideas | - Providing creative spaces (both, physical and digital) that promote agile and innovative work<br>- Provision of required technologies for innovation generation<br>- Providing interfaces between the real world and the digital twin (e.g. VR) to promote further developments in the Smart City<br>- Provision of an innovation-promoting hierarchy structure within the lab<br>- Use of collaboration tools to bring relevant developers together<br>- Provision of possibilities for testing the innovations under real physical conditions or under simulation conditions in the digital twin |
| | Business Incubator | Consulting services, that support business start-ups in achieving marketability | - Support of start-ups through external know-how, coaching and consulting<br>- Provision of work surfaces<br>- Assistance in the procurement of contacts and capital<br>- Support for start-ups by experts to develop a market-ready business model<br>- Providing best practice approaches from the business world for successful further development |
| | Smart Business Environment | Encourage innovation and successful business models by providing an optimal working environment for all types of work | - Providing the required working environment for each worker in the city based on human requirements, the type of work and the occupancy of spaces<br>- Provision of multifunctional rooms, which can be adapted to different types of work or to different numbers of people<br>- Flexible space allocation on a daily basis, optimizing the utilization of available space in the city<br>- Integration into the city's overall space concept<br>- Use of a space allocation technology (e.g. smartphone) that is accessible to everyone |

| Segment | Sub-Segment | Description | Requirements |
|---|---|---|---|
| Smart Economy | Smart Regulation | Securing the innovative ability, attractiveness, competitiveness and further development of the city through positively influencing innovation and economic regulation | - see Smart Policies<br>- Development of a best practice approach for innovation regulation as well as for regulatory approaches to positively influence the economic development of the city<br>- Agile further development of the guidelines through participation of firms and individuals |
| Smart Data | Smart Privacy (system-based) | Securing the privacy and autonomy of people by providing the required solutions | - Providing solutions to allow people to decide for themselves about their data, thus ensuring their specific privacy requirements<br>- Use of technology that maximizes the privacy of people through anonymization<br>- Use of secure network technologies to prevent data theft<br>- Ensure a balance between privacy and data availability |
| | Smart Data Management | Implementing an accepted data management administration system that protects people's privacy and meets the required technical standards to enable processing of Big Data and make them usable | - Use of secure network technologies to protect the collected data as well as the privacy of people from unauthorized access<br>- Consideration of the individually defined requirements of people during data input<br>- Administration of exclusively anonymized data<br>- Creation of the interface between data input (IoT, direct data input by humans) and data access<br>- Data management by an accepted and trustworthy institution<br>- Detailed evaluation of whether data is managed internally or externally (depending on know-how, see Chapter 3.4.2)<br>- Provision of sufficient storage capacity and computing power, as well as ensuring current technical standards to ensure a comprehensive digital twin as a starting point for the further development and for optimization of the MSP<br>- Availability of a suitable geolocation database |

| Segment | Sub-Segment | Description | Requirements |
|---|---|---|---|
| Smart Data | Smart Machine-Human Interaction | Ensuring a people-centered Smart City through comprehensive indirect and direct two-way communication between people and technology | - Comprehensive two-way interaction (from human to technology and from technology to human) options in order to maximize data input into the digital twin and two-way advises<br>- Use of various communication options to enable permanent interactions for everyone<br>- Use of direct communication components (smartphones, tablets, etc.) for interaction between people and city, allowing people to directly request the system to perform actions, and, if necessary, to replace individual data<br>- Use of indirect communication possibilities (motion sensors, etc.) to identify patterns in human behavior in order to control city operations appropriately, thus maximizing comfort<br>- Use of digital assistants to enable social interactions<br>- Decision-making power belongs to humans, i.e. they can influence what kind of data they want to share and can overwrite the data at any time<br>- Exclusive processing of anonymous data<br>- Educating people about handling of communication |
| | Digital Twin | Comprehensive digital mapping of physical and real objects of the Smart City within the digital twin, which independently optimizes and manages the operation of the city on the basis of data evaluation technology. In addition, it serves as a source for new business models | - Provision of sufficient storage capacity and computing power as well as ensuring current technical standards to secure a comprehensive digital twin<br>- Data within the digital twin must be accessible to serve as a starting point for innovation as well as to enable the further development of existing businesses<br>- Complexity of the city must be able to be mapped<br>- Digital twin must be scalable to adapt to urban developments<br>- Digital twin must be confidential and impartial through data security<br>- Use of advanced data evaluation technology (e.g. AI) to manage daily operations and to continuously develop the city's operations based on scenario analysis and pattern recognition<br>- Education of people about use of data |

| Segment | Sub-Segment | Description | Requirements |
|---|---|---|---|
| Smart Data | Smart Data Access | Use of open data approaches to exploit the full potential of economic growth through access by everyone | - Exclusive access to anonymized data and in line with Smart Privacy<br>- Use of completely open data approaches to enable access for everyone<br>- Unlimited access to data for everyone without restrictions based on data rights or data formats used and without financial compensation<br>- Providing analysis tools for the development of innovations or the further development of business models<br>- Prevent government or individual organizations from influencing data access |
| Smart Mobility | Smart Inner-City Mobility | Creation of a climate-neutral, multi-modal and intelligently utilization-optimized inner-city transport concept | - Use of climate-neutral and multi-modal transport options<br>- Approaches regarding optimized utilization of transport options (car-pooling, car-sharing)<br>- Development of mobility as a service concept<br>- Ensuring the affordability of transport<br>- Use of intelligent traffic control systems<br>- Creation of a fully networked and self-optimizing system<br>- Initiatives to promote the acceptance and education of people about new traffic concepts<br>- Consider scaling options in the design<br>- Use of modular construction between road and public transport to ensure scalability |
| | Smart Regional Mobility | Ensuring a climate-neutral transport and intelligent connection to the city of Maun | - see Smart Inner-City Mobility<br>- Interface to transport facilities of the other parts within the city Maun |

*Table 2: Maun Science Park segments*

| | | Smart Energy | | | | Smart Farming | | | Smart Water | | | | Smart People | | | Smart Government | | | Smart Environment | | | | | Smart Living | | | Smart Economy | | | | | Smart Data | | | | | Smart Mobility | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Smart Production | Smart Grid | Smart Storage | Smart Consumption | Smart Irrigation | Smart Harvesting Security | Smart Automation | Smart Collection | Smart Storage | Smart Consumption | Smart Recycling | Smart Education | Smart Collaboration | Smart Privacy | Smart Decisions | Smart Policies | Smart Transparency | Smart Waste | Smart Human-Wildlife | Smart Resources | Smart Space Management | Smart Pollution Management | Smart Building | Smart Health | Smart Safety | Co-Creation Network | Innovation Lab | Business Incubator | Smart Business Environment | Smart Regulation | Smart Privacy | Smart Data Management | Smart Data Access | Digital Twin | Smart Machine-Human interaction | Smart Inner-City Mobility | Smart Regional Mobility |
| **Smart Energy** | Smart Production | | x | x | x | | | | | | | | | | | | | | | | x | x | x | | | | | | | | | | | | x | | x | x |
| | Smart Grid | x | | x | x | | | | | | | | | x | | | x | | | | | | | | | | | | | | | | | | x | | x | x |
| | Smart Storage | x | x | | x | | | | | | | | | | | | | | | | | x | | | | | | | | | | | | | x | | x | x |
| | Smart Consumption | x | x | x | | | | | | | | | x | | | | | | | | | | x | | | | | | | | | | | | x | x | x | x |
| **Smart Farming** | Smart Irrigation | | | | | | x | x | x | x | x | x | | | | | | | | | | | | | | | | | | | | | | | x | | | |
| | Smart Harvesting Security | | | | | x | | x | | | | | | | | | | | | x | | | | | x | | | | | | | | | | x | | | |
| | Smart Automation | | | | | x | x | | | | | | | | | | | | | | | | | | | | | | | | | | | | x | | | |
| **Smart Water** | Smart Collection | | | | | x | | | | x | x | x | | | | | | | | | x | x | | | x | | | | | | | | | | x | | | |
| | Smart Storage | | | | | x | | | x | | x | x | | | | | | | | | x | x | | | x | | | | | | | | | | x | | | |
| | Smart Consumption | | | | | x | | | x | x | | x | x | | | | | | | | x | | | | x | | | | | | | | | | x | x | | |
| | Smart Recycling | | | | | x | | | x | x | x | | | | | | | | x | | x | | | | x | | | | | | | | | | x | | | |
| **Smart People** | Smart Education | | | | x | | | | | | x | | | x | x | x | x | x | x | x | x | x | x | | x | x | x | x | x | x | x | x | | x | x | x | x | x |
| | Smart Collaboration | | x | | | | | | | | | | x | | x | x | x | x | | | | x | | | | x | x | x | x | x | x | x | x | x | x | x | x | x |
| | Smart Privacy | | | | | | | | | | | | x | x | | | x | x | | | | | | | | x | | | | | x | x | x | x | x | x | | |
| **Smart Government** | Smart Decision | | | | | | | | | | | | x | x | | | x | x | | | | | | | | | | | | | | | | | x | | | |
| | Smart Policies | | x | | | | | | | | | | x | x | x | x | | x | | | | | | | | | | | | | | | | | x | | | |
| | Smart Transparency | | | | | | | | | | | | x | x | x | x | x | | | | | | | | | | | | | | | | | | x | | | |
| **Smart Environment** | Smart Waste | | | | | | | | | | | x | x | | | | | | | | x | | | | x | | | | | | | | | | x | | | |
| | Smart Human-Wildlife | | | | | | x | | | | | | x | | | | | | | | | x | | | | x | | | | | | | | | x | x | | |
| | Smart Resources | x | | | | | | | x | x | x | x | x | | | | | | x | | | | x | | | | | | | | | | | | x | | | |
| | Smart Space Management | x | | x | | | | | x | x | | | x | x | | | | | | x | | | | | | | | | | x | | | | | x | x | x | x |
| | Smart Pollution Management | x | | | x | | | | | | | | x | | | | | | | | x | | | | x | | | | | | | | | | x | | x | x |
| **Smart Living** | Smart Building | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| | Smart Health | | | | | | x | | x | x | x | x | x | | | | | | x | | | | x | | | x | | | | | | | | | x | x | x | x |
| | Smart Safety | | | | | | | | | | | | x | x | x | | | | | x | | | | | x | | | | | | | | | | x | x | x | x |
| **Smart Economy** | Co-creation network | | | | | | | | | | | | x | x | | | | | | | | | | | | | | x | x | x | x | | x | | x | | | |
| | Innovation Lab | | | | | | | | | | | | x | x | | | | | | | | | | | | | x | | x | x | x | | x | | x | | | |
| | Business Incubator | | | | | | | | | | | | x | x | | | | | | | | | | | | | x | x | | x | x | | x | | x | | | |
| | Smart Business Environment | | | | | | | | | | | | x | x | | | | | | | | x | | | | | x | x | x | | x | | x | | x | | | |
| | Smart Regulation | | | | | | | | | | | | x | x | x | | | | | | | | | | | | x | x | x | x | | x | x | x | x | | | |
| **Smart Data** | Smart Privacy | | | | | | | | | | | | x | x | x | | | | | | | | | | | | | | | | x | | x | x | x | x | | |
| | Smart Data Management | | | | | | | | | | | | | x | x | | | | | | | | | | | | x | x | x | x | x | x | | x | x | x | | |
| | Smart Data Access | | | | | | | | | | | | x | x | x | | | | | | | | | | | | | | | | x | x | x | | x | x | | |
| | Digital Twin | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | | x | x | x | x | x | x | x | x | x | x | | x | x | x |
| | Smart Machine-Human Interaction | | | | x | | | | | | x | | x | x | x | | | | | x | | x | | | x | x | | | | | | x | x | x | x | | x | x |
| **Smart Mobility** | Smart Inner-City Mobility | x | x | x | x | | | | | | | | x | x | | | | | | | | x | x | | x | x | | | | | | | | | x | x | | x |
| | Smart Regional Mobility | x | x | x | x | | | | | | | | x | x | | | | | | | | x | x | | x | x | | | | | | | | | x | x | x | |

*Figure 12: Maun Science Park segments interactions*

**Prioritization of the segments**

The defined concept includes all desirable solution areas within the MSP. However, since technological and financial possibilities are often limited in projects, the focus on individual areas might be relevant in further project steps. To enable prioritization, the following Figure 13 qualitatively evaluates the economic affordability[233] with the impact[234] of the individual sub-segments based on the discussion with HERO. Thereby, Quadrant I has the highest relevance.

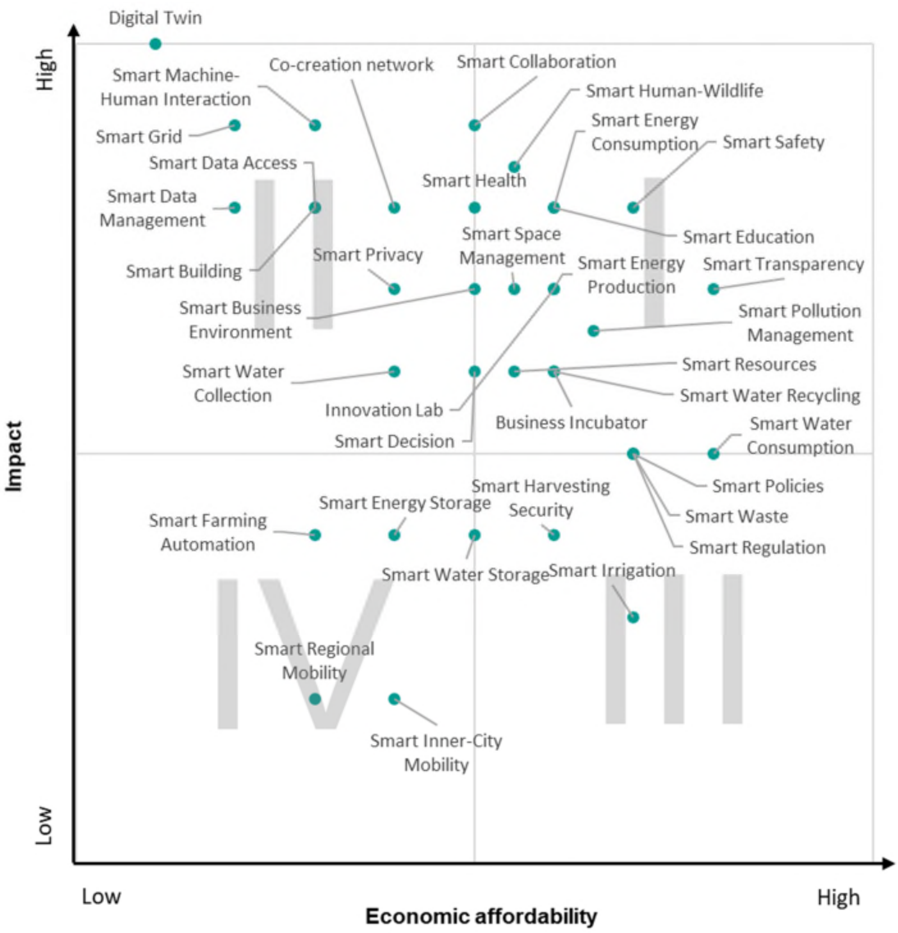


*Figure 13: Maun Science Park segments: Economic affordability vs. impact*

It should be noted that Figure 13 is only a qualitative evaluation. In order to quantify this, explicit solutions have to be defined for the individual sub-segments. Furthermore, according to HERO, in Botswana, an additional assessment of behavior affordability[235] and accessibility[236] are

[233] Economic affordability describes the degree of access people have to a specific service on the basis of financial conditions. The more economically affordable a service, the more people have access based on costs and their financial resources.
[234] Impact describes the extent of the positive influence of components on existing challenges and problems as well as on humans and their environment. The higher the impact, the more advantageous the service.
[235] Behavior affordability describes the adaptability of human behavior based on their existing behavior and their willingness. The higher the behavior affordability, the less effort is required to change or to adapt individuals' existing behavior.
[236] Accessibility describes the ability of individuals to access a service and benefit from its features. The higher the accessibility, the more or easier people can use the product based on their skills.

relevant factors, which will require further research. Moreover, the superordinate factors, which are discussed within Chapter 5.2.3, are regarded as absolutely essential and thus have to be integrated into the concept even if they are not positioned in Quadrant I in Figure 13. In addition, the different sub-segments are interconnected (see Figure 12).[237] This applies between segments of the Smart City and the Smart Buildings (see Figure 14) as well. As a result, some segments are highly dependent on others and thus function only partially without interaction with the other specific segment. This further complicates prioritization through the qualitative evaluation of impact and economic affordability and has to be considered in further project steps.

### 5.2.2 Smart Building segments in Maun Science Park

As buildings are a key factor in urban infrastructure, the second part of the synthesis concept is the Smart Building approach for MSP. The following chapter deals with the Smart Building segments.

**Description and requirements of the segments**

As in the case of the Smart City MSP concept, Figure 11 already shows core areas for the Smart Building concept. Based on the same method as described in Chapter 5.2.1, these three core areas are further divided (three main segments, 16 sub-segments) as well as the sub-segments and their requirements are defined in Table 3. Furthermore, the interactions of the areas in relation to the Smart City segments are shown in Figure 14.

[237] cf. Bakker 2020

| Segment | Sub-Segment | Description | Requirements |
|---|---|---|---|
| Smart Control | Smart Operations | The system learns on the basis of user behavior and the building environment, enabling an automated and intelligent control of all building operations in order to maximize comfort and safety as well as to optimize energy consumption | - Focus on intelligent control and management combined with maximizing comfort and safety<br>- Use of AI for the intelligent control of all building operations based on human requirements and pattern recognition and for identifying optimization potentials<br>- Efficient and intelligent use of building operations to increase the life cycle while reducing energy consumption<br>- Direct and indirect communication between building and people as well as implementation of intervention possibilities for people to focus on human needs<br>- Communication between system components to maximize the overall benefit<br>- Usage of security components to ensure privacy of people<br>- Building operations consider conversion and expansion possibilities to ensure usability over the life cycle |
| | Smart Human-Building Interaction | Ensuring people-centered building operations through comprehensive indirect and direct two-way communication between people and technology | - Comprehensive two-way interaction (from human to building and from building to human) options (direct and indirect) in order to maximize data input into the digital twin, two-way advises and comfort within the buildings<br>→ For further aspects see Smart City segments → Smart Data → Smart Machine-Human Interaction |
| | Smart Buildings-City Communication | Ensuring comprehensive interaction between Smart Buildings and the city through data exchange, allowing buildings to become a consistent part of a city environment, which further optimizes the overall operation of all infrastructure components of the city | - Implementation of buildings in the overall system of the city to improve the overall performance within the society<br>- Real-time data exchange to minimize response times<br>- Ensuring that both components – building and city – can collect and analyze data through IoT systems and AI<br>- Create a consistent environment and profitable interaction as well as manage peak times (e.g. energy consumption) by exchanging and analyzing data |
| | Smart Privacy (building-based) | Securing the privacy and autonomy of people by providing the required solutions within the buildings | - Building structure and intelligent alignment of jalousies ensure privacy within the building from the its environment<br>→ For aspects about online and data security see Smart City segments → Smart Data → Smart Privacy |

| Segment | Sub-Segment | Description | Requirements |
|---|---|---|---|
| Smart Energy | Smart Energy Production | Ensuring a renewable energy supply for the buildings at all times | - Ensuring an energy supply for buildings that is as self-sufficient as possible, even in peak times<br>- Dimensioning and alignment in consideration of the house's specific boundary conditions as well as of the total energy demand of the building system<br>→ For further aspects see Smart City segments → Smart Energy → Smart Production |
| | Smart Energy Storage | Application of a sustainable storage system as a balancing variable between energy production and consumption that ensures a continuous energy supply | - Dimensioning of the capacity in terms of balancing energy production and consumption of the buildings in peak times<br>- Integration into the city's overall system in order to become part of an overall buffer of the smart grid<br>- Intelligent energy extraction and addition to the smart grid in order to secure both, the buildings supply as well as the overall supply of the city, and to enable economic possibilities<br>→ For further aspects see Smart City segments → Smart Energy → Smart Storage |
| | Smart Energy Consumption | Implementation of energy-efficient smart consumption systems and components in order to minimize the total energy demand of the buildings | - Minimize switch-on times through intelligent control of the systems (see Smart Operations)<br>→ For further aspects see Smart City segments → Smart Energy → Smart Consumption |
| | Smart Ventilation and Cooling | Smart control of the ventilation and cooling system to ensure comfortable temperatures while minimizing energy consumption | - Use of energy-saving, efficient and sustainable ventilation/air conditioning systems<br>- Intelligent ventilation based on $CO_2$ concentration in the air, number of people in the room, activities and habits of people as well as outside temperature<br>- Intelligent temperature control within the building by using cool outside temperatures at night → minimizing the operating time of the air conditioning system<br>- Education of people about the use of air conditioning systems |

| Segment | Sub-Segment | Description | Requirements |
|---|---|---|---|
| Smart Energy | Smart Sun Management | Intelligent control and planning of systems to obtain the maximum benefit from solar radiation and light entering the building while minimizing the negative impact of heat entering the building | - Minimizing direct sunlight while maximizing the input of natural light within the building<br>- Intelligent solar management as part of ensuring thermal comfort<br>- Automated and intelligent alignment of blinds based on the position of the sun, the heat within the building and the movements of people within the building<br>- Intelligent planning of the orientation of the building, the rooms within it and its components (e.g. PV in the north-east, large window fronts in the south, optimal window/wall ratio for energy management)<br>- Education of people regarding the impact of intelligent sun management |
| | Smart Warm Water \| Heating | Integration of sustainable heat production systems in buildings and intelligent and efficient utilization of the generated heat | - Use of energy-saving, efficient and sustainable heating systems appropriate to the specific location of MSP<br>- Use of intelligent technologies to minimize the switch-on times of the systems and to provide hot water exactly where and when it is required<br>- Intelligent and holistic temperature management within the building, minimizing the use of heating systems<br>- Education of people regarding heating and intelligent temperature management<br>- Overall consumption monitoring to derive optimization measures and to increase people's awareness of their consumption |
| Smart Life Cycle Management | Smart Materials | Use of sustainable, durable and location-appropriate building materials | - Use of local building materials appropriate to the location<br>- Use of sustainable, durable and recyclable materials (total life cycle approach, consideration of grey energy in relation to life cycle savings)<br>- Use of materials that has positive influence on the energy management within the operating phase based on the site conditions (e.g. much sun and heat → more cooling/ventilation than heating → heat-absorbing materials) |

| Segment | Sub-Segment | Description | Requirements |
|---|---|---|---|
| Smart Life Cycle Management | Smart Construction | Intelligent construction of the buildings to ensure usability over the life cycle and with regard to energy management and scalability | - Modular design to enable scalability and transferability to other projects in Botswana (providing best practice)<br>- Building structure suitable for the environment (e.g. much sun and heat → more cooling/ventilation than heating → heat-absorbing structure; optimal wand/window ratio)<br>- Alignment of the building in accordance with segments Smart Sun Management and Smart Energy Production<br>- Building structure considers conversion and expansion possibilities to ensure usability over the life cycle |
| | Smart Space Management | Optimizing space utilization over the life cycle of the building through multiple use, reuse options and intelligent space allocation | - Connection to the city's space utilization concept<br>- Integration of multi-purpose use options for less frequent use cases (e.g. fitness, cinema, guest room)<br>- Optimal utilization of the sealed and built-up area<br>- Utilization of individual rooms only at times of day when it makes sense from a cost and energy consumption point of view, as too much cooling may be required to make these rooms comfortable<br>→ Integration of approaches for (digitally) re-programmable space (see Chapter 5.3) |
| | Smart Maintenance | Predictive maintenance is enabled by monitoring building systems in order to ensure continuous building operation | - Usage of location appropriate, deliverable and durable components and technologies<br>- Continuous monitoring and control of the systems in order to proactively purchase and replace components |
| | Smart Conversion \| Extension | Buildings are intelligently designed in order to allow conversion or expansion to optimize the utilization of space over the life cycle | - Consider conversion possibilities in the design to ensure the utilization of space over the life cycle<br>- Consider expansion possibilities in the design as well as extension options within building operations to achieve scalability of the project and to allow the use of the building with the next generation according to traditional lifestyles<br>→ For further aspects see segments Smart Construction and Smart Operations<br>→ Integration of approaches for (digitally) re-programmable space (see Chapter 5.3) |

| Segment | Sub-Segment | Description | Requirements |
|---|---|---|---|
| Smart Life Cycle Management | Smart Water | Use of an intelligent and efficient system for collection, storage and consumption of water based on use-specific water quality dimensions in order to reduce the external water input | - Integration into the city's multidimensional water collection system (e.g. rainwater collection on the roof)<br>- Smart design and space utilization of facilities (collection and storage) in order to minimize the environmental impact (e.g. use of the roof area for water extraction or use of the subsoil of the built-up area as storage)<br>- Use of quality-assured storage systems, decentralized water treatment systems and low consumption systems<br>- Implementation of types of use where different water qualities can be applied in order to avoid always having to provide drinking water quality<br>- Overall consumption monitoring to derive optimization measures and to increase people's awareness of their consumption<br>- Education of people regarding water use |

*Table 3: Smart Building segments*

| | | Smart Control | | | | Smart Energy | | | | | | Smart Life Cycle Management | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Smart Operations | Smart Human-Building Interaction | Smart Buildings-City Communication | Smart Privacy | Smart Energy Production | Smart Energy Storage | Smart Energy Consumption | Smart Sun Management | Smart Ventilation and Cooling | Smart Warm Water \| Heating | Smart Materials | Smart Construction | Smart Space Management | Smart Maintenance | Smart Conversion \| Extension | Smart Water |
| **Smart Energy** | Smart Production | | | | | x | x | x | | | | | | | | | |
| | Smart Grid | | | | | x | x | x | | | | | | | | | |
| | Smart Storage | | | | | x | x | x | | | | | | | | | |
| | Smart Consumption | | | | | x | x | x | x | x | x | | | | | | |
| **Smart Farming** | Smart Irrigation | x | | | | | | | | | | | | | | | x |
| | Smart Harvesting Security | | | | | | | | | | | | | | | | x |
| | Smart Automation | | | | | | | | | | | | | | | | |
| **Smart Water** | Smart Collection | | | | | | | | | | | | | | | | x |
| | Smart Storage | | | | | | | | | | | | | | | | x |
| | Smart Consumption | x | x | x | | | | | | | | | | | | | x |
| | Smart Recycling | | | | | | | | | | | | | | | | x |
| **Smart People** | Smart Education | x | x | x | x | | | x | x | x | x | x | x | x | | x | x |
| | Smart Collaboration | x | x | x | x | x | x | x | | | | | | x | | x | |
| | Smart Privacy | x | x | x | x | | | | | | | | | | | | |
| **Smart Government** | Smart Decision | | x | x | | | | | | | | | | | | | |
| | Smart Policies | | | | x | | | | | | | | | | | | |
| | Smart Transparency | | | | x | | | | | | | | | | | | |
| **Smart Environment** | Smart Waste | | | x | | | | | | | | x | x | | x | | |
| | Smart Human-Wildlife | | | x | | | | | | | | | | | | | |
| | Smart Resources | | | x | | x | | | | | | x | x | | x | | x |
| | Smart Space Management | | x | x | | | | | | | | | x | x | | x | |
| | Smart Pollution Management | x | | | | x | | | | x | x | x | x | | | | |
| **Smart Living** | Smart Building | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| | Smart Health | x | | | | | | | | | | x | x | | | | x |
| | Smart Safety | | | | x | | | | | | | | | | | | |
| **Smart Economy** | Co-creation network | | | | | | | | | | | | | | | | |
| | Innovation Lab | | | | | | | | | | | | | | | | |
| | Business Incubator | | | | | | | | | | | | | | | | |
| | Smart Business Environment | x | x | x | | | | | | | | | x | x | | x | |
| | Smart Regulation | x | x | x | x | | | | | | | | | | | | |
| **Smart Data** | Smart Privacy | x | x | x | x | | | | | | | | | | | | |
| | Smart Data Management | x | x | x | x | | | | | | | | | | | | |
| | Smart Data Access | x | x | x | x | | | | | | | | | | | | |
| | Digital Twin | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x | x |
| | Smart Machine-Human Interaction | x | x | x | x | | | | | | | | | | | | |
| **Smart Mobility** | Smart Inner-City Mobility | | | | | | | | | | | | | | | | |
| | Smart Regional Mobility | | | | | | | | | | | | | | | | |

*Figure 14: Smart City and Smart Building segments interactions*

**Prioritization of the segments**

Similar to the concept of the Smart City MSP, the thesis prioritizes the Smart Building sub-segments as well. This prioritization results from the discussion with the expert BAKKER. The following Figure 15 shows the prioritization by comparing economic affordability and impact, whereby the same remarks and definitions as in Chapter 5.2.1 are to be considered.

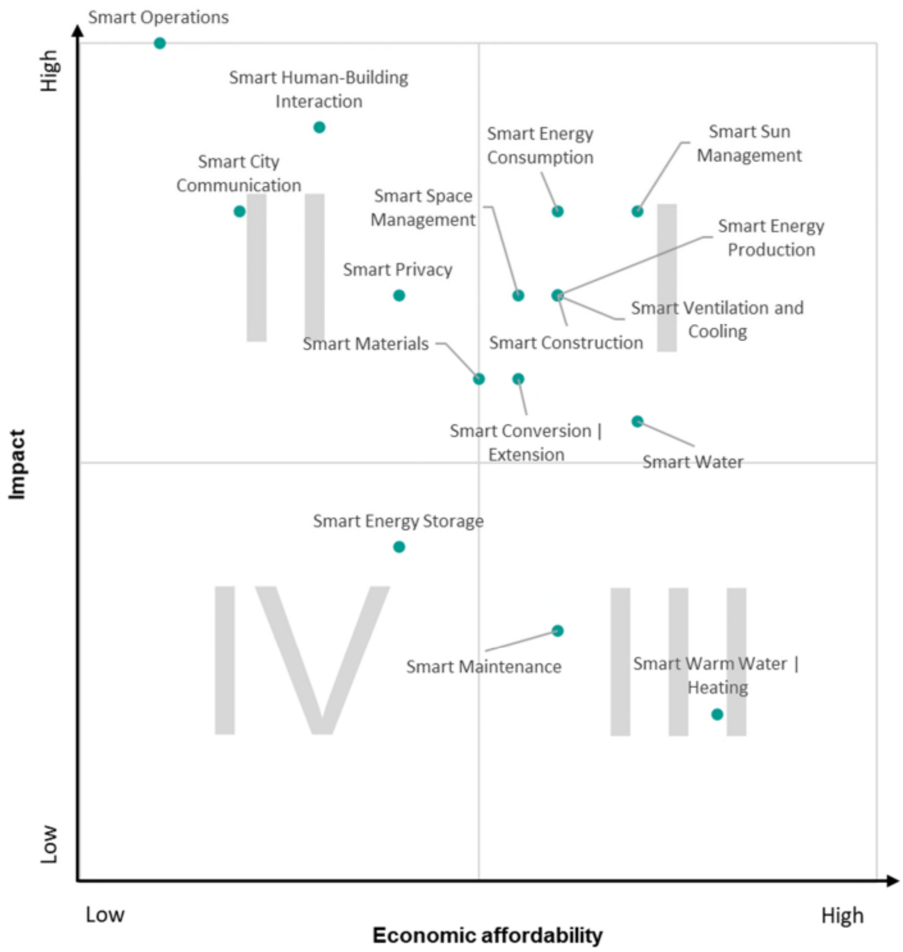


*Figure 15: Smart Building segments: Economic affordability vs. impact*

### 5.2.3 Discussion of important overall conditions for the concept

In Chapter 5.2.1 and 5.2.2 a prioritization of the individual sub-segments was demonstrated. However, some superordinate aspects within the MSP have to be considered to ensure its functionality, practicability and its operation. These are described in the following chapter. Furthermore, a recommendation on the potential Smart City development stage is given.

**Smart People**

As already identified in the literature research in Chapter 2 and implemented in the MSP framework (Figure 11), people are the key element of a Smart City and thus the focus of MSP development. In addition, besides the segment Digital Twin, the Smart People sub-segments have the most interaction points within the synthesis concept (Figure 12 and Figure 14). According to HERO, particularly two elements are to be emphasized from the human perspective – trust and community.[238]

In the context of the introduction of new technologies, it is essential that people establish trust towards the new technologies in order to enable a successful implementation.[239] Thereby, the core element is the education of people. People have to be instructed about the management and usage of their data. This enables them to gain control of their own data and thus generate trust in the technology. In this context, it is important that within the smart data concept human intervention possibilities are available (see Chapter 3.4.1 and sub-segments Smart Privacy). Furthermore, education is a key aspect in terms of ensuring a smart economy as well, especially in terms of a co-creation network based on collective intelligence. People have to learn about technologies and their functions in order to participate proactively in the development process. The second aspect relating to trust is the privacy of people, as already considered within the segments Smart People and Smart Data. People need to be convinced that data is managed and used according to their expectations. The aspects concerning data are explained in more detail in the next section due to their high relevance. Furthermore, in the context of privacy, it should be noted that general security – both, data security and physical security (sub-segment Smart Safety) – represents the basis, since privacy is impossible without security. Another factor for ensuring trust is transparency. According to HERO, people have to be informed about developments and decisions in a way that is understandable and suitable for them. In particular the sub-segment Smart Transparency, but also the category Smart Education has a key role in this process again. In addition, reliability of systems and individual components are relevant. Due to an increased variance within functionality, the resulting uncertainty leads to a significant reduction in functionality, consumption and acceptance of the newly introduced system. Therefore, durable and efficient systems are required throughout all solution areas. The final aspect of establishing trust is independent certification and attestations. This aspect assumes a relevant role within the scalability as well. Certification results in the development of specific standards and best practice approaches. These enable scalability, since these are transferable to other projects.[240]

In Botswana, the community aspect assumes a significant role, as collective approaches are widely practiced throughout Sub-Saharan Africa. In this context, Kgotla traditionally serves as a key element in Botswana. Thereby, people of a community meet and talk about specific issues confronting them. Therefore, collaboration and collective decision-making will remain

[238] cf. Hero 2020
[239] cf. Bakker 2020b; Hero 2020
[240] cf. Hero 2020

an integral part of Botswana's life in the future. Furthermore, collaboration is essential within the segment Smart Economy, as it enables people to co-create on the basis of collective intelligence. As a result, the development of the sub-segment Smart Collaboration is an essential issue from a traditional as well as from a Smart City perspective.[241]

**Smart Data**

As already described within Chapters 2.3.2 and 4.3, an advanced use of data can be an element to differentiate the MSP from other projects. Moreover, it has already been shown that data and its use are essential for the functionality of a Smart City as well. Consequently, aspects concerning data are discussed in the following section.

Within Figures 12 and 14, it has been identified, that the sub-segment Digital Twin has a direct relationship with all other solution areas. This is due to the fact, that for a highly efficient Smart City, all physical elements have to be digitally mapped in order to optimize all operations and ensure functionality through the digital representation (for more information see Chapter 3.3). Therefore, the segment Digital Twin is the key component of the MSP. In order to enable these processes, all operations within the other sub-segments have to be digitally mapped – their entirety has to form a sensing fabric. In this context, IoT technologies are essential. As described in Chapter 3.3, IoT solutions form the link between the digital and physical world. Therefore, according to HERO, these are essential, as they allow "blurring the line between digital and physical world"[242]. For this purpose, different devices – sensors and actuators – are used to record operations and execute actions. It should be noted that, besides indirect communication within the sensing fabric, direct communication between the human and the digital twin is required in order to ensure an appropriate level of Smart City operations. Thereby, smartphones can form a key feature, as these devices are available to almost everyone in cities and can accordingly be categorized as affordable (for further possibilities see Chapter 3.5). As a consequence, the sub-segments Smart Human-Machine Interaction (Smart City) and Smart Building-Human Interaction (Smart Building) including important components as well. In this context it is important that direct instructions become less frequent through continuous learning of the system and on the basis of indirect communication. According to HERO, another important aspect of digital mapping in the digital twin is the geolocation database. This has to ensure that data is correctly classified according to its origin, thus preventing errors.[243]

In the context of data, critical questions regarding data management, data ownership and data access have to be clarified as well. These issues are important, because they contribute to

[241] cf. Hero 2020
[242] Hero 2020
[243] cf. Hero 2020

ensure privacy and acceptance. In Chapter 3.4 these aspects were discussed. Within the Smart City concept in Table 2, requirements for the specific sub-segments (Smart Data Access and Smart Data Management) were defined. However, further research based on the requirements of the local population and local regulations is required to develop suitable solutions.

The final aspect to consider within the data issue is the communication between the Smart City and the Smart Buildings within the city. In Chapter 2.3.2, the lack of exchange of data between these elements leads to the identification that data is a distinguishing feature compared to other projects. However, exactly this type of communication has a huge potential, since Smart Buildings can exert a significant influence on their environment due to their large infrastructure share and therefore contribute to the general optimization – especially of consumer systems (e.g. energy). As a result, the sub-segments Smart Building (Smart City) and Smart Buildings-City Communication (Smart Building) are fundamental for project success.

**Classification of the MSP in Smart City development stages**

In the context of developing an overall concept, it is important to focus on a specific Smart City development stage in order to be able to integrate and develop technologies and solutions appropriately. In Chapter 2.1.3 three main development stages have been identified. Smart City 1.0 is not targeted within the MSP, as the project and the Botswanan boundary conditions require attention to the overall context, especially in the context of people's well-being. The synthesis concept already considered this fact by addressing local challenges and requirements. As generally recommended in Chapter 2.1.3, the MSP should first achieve a combination between Smart City 2.0 and 3.0. This implies that the administration develops a network of technologies that interacts simultaneously with co-creation approaches of residents within the city. This is due to the fact that today's global technological development as well as the current level of development of the Botswanan population and economy does not allow an exclusive Smart City 3.0 so far. However, an exclusive stage 2.0 is not desirable as well, since the combination offers the potential for the provided system to evolve independently through collective intelligence and collaboration between people (and administration), as the population, firms and administration continues to develop. In this process, a continuous development towards the highest stage of development can be supported.

In addition, it should be noted that scalability and transferability of the overall concept is a key objective of the MSP. Therefore, all segments of MSP should be aware of this objective, e.g. within the Smart Construction segment through a modular design. In this context, it is particularly important to ensure that all technologies of the overall system are transferable.

## 5.3 Approaches of (digitally) re-programmable space including added values

The second main goal of the thesis is the development of (digitally) re-programmable space based on the Botswanan and MSP specific requirements as well as the synthesis concept. Sections 5.3.1 to 5.3.4 describe the different approaches and point out their added value. Thereby the approaches are divided into four categories. The first two categories include approaches to multi-purpose use of space. The third category describes approaches for the conversion of space over the life cycle. The last aspect in Chapter 5.3.4 extends the original approach of (digitally) re-programmable space mentioned in Chapter 3.1. Finally, in Chapter 5.3.5 requirements for the described approaches are defined and, if necessary, IoT solutions are derived. In this context it needs to be noted that the approaches are only described exemplarily. For the actual integration, detailed planning and evaluation is necessary.

### 5.3.1 Approaches of multi-purpose use of building space

The following chapter describes approaches for the multi-purpose use of space in buildings within the daily routine. These are briefly described and their added value is illustrated.

**Multifunctional rooms in residential buildings**

Residential buildings often contain rooms (e.g. fitness, guest, cinema or home office room) for irregular use cases. Consequently, these rooms are underutilized. In order to optimize the utilization of such spaces, a concept should be used that combines less regular types of use within a single room. The primary element of these multifunctional rooms is an intelligently planned design that enables different types of use. Furthermore, the building operations (lighting, ventilation, etc.) adjust in real time and automatically to the type of use identified by the building system. As a result, such multifunctional rooms minimize the space required in residential buildings as well as optimize energy and resource consumption of buildings, resulting in economic advantages and an optimized impact on the environment. The described smart home in Hauzenberg in Chapter 2.2.2 can be used as a reference example for such solutions.

**Restaurant with flexible adaptable room design**

According to BOALOTSWE, restaurants in Botswana are primarily visited in the evening and are underutilized in the morning and afternoon.[244] Therefore, the use of space within restaurants has to be optimized beyond the operating hours in the evening. In order to solve this problem, the MSP can integrate an approach for a multi-purpose use of space within the restaurant. The main feature of the approach are intelligent room separation elements. This enables the restaurant to be used partly as a cafeteria in the daytime, while at the same time the other separate parts of the room can be used for meetings or as study rooms. On weekends, the room

[244] cf. Boalotswe 2020

separation elements can be used to separate the room for private events such as weddings as well. Figure 16 shows an exemplary graphical illustration of the use cases.

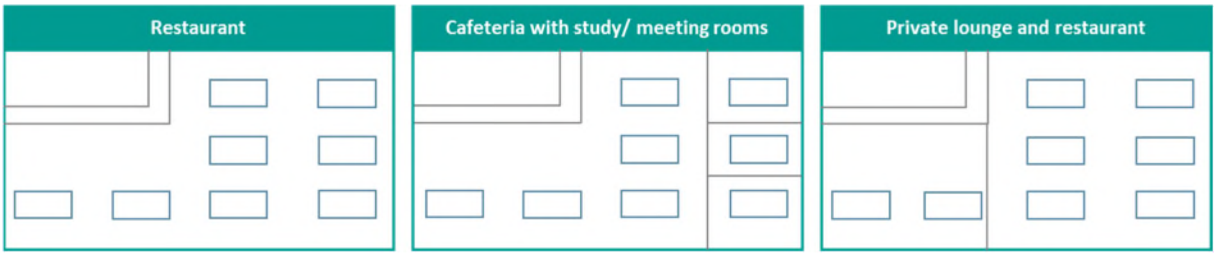


*Figure 16: Exemplary representation of restaurant with flexible adaptable room design*

The various configurable rooms can be reserved via an online booking system, for example by using smartphones. Besides the desired room separation, the building operations (lighting, ventilation, etc.) are automatically adapted to the specific use based on the booking information and habits of the users. As a result, flexible room design and intelligent building operations enable a multi-purpose use of restaurants. This optimizes the utilization of space during the week, minimizes the space required and reduces the overall energy and resource consumption.

**Combined school and office rooms**

Within the MSP, rooms are to be created especially for school and business. Both applications require different types of rooms – small and large meeting rooms, individual workstations, large and small lecture rooms or group workrooms. However, due to the size of the MSP's first stage of development and the variety of rooms required, optimal utilization cannot be achieved with a physical separation of school and business. Therefore, the following concept intends to create proximity and a combined area between school and office rooms. This is to be coupled with intelligent room design on the basis of room separation elements, which enables a multi-purpose use of space. For example, a room can switch between the use cases classroom, large meeting room or learning room. Figure 17 illustrates exemplarily such a configuration possibility.

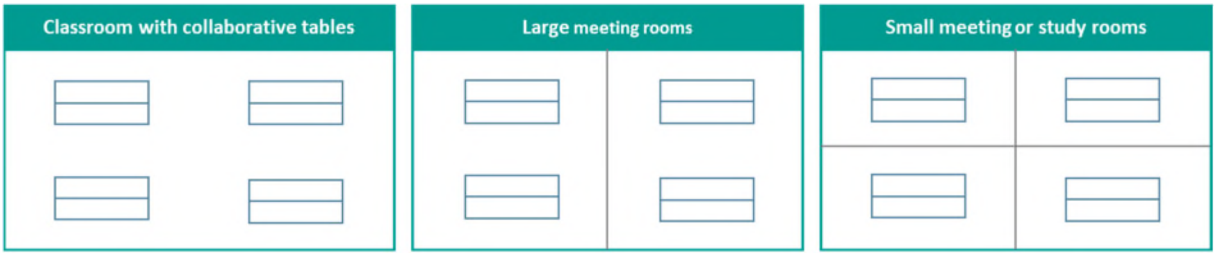


*Figure 17: Sample illustration of combined school and office rooms*

As in the case of the restaurant, it has to be possible to reserve the rooms via an online booking system and the building operations have to be automatically adapted to the selected applications. For example, this will ensure that only rooms that are actually in use are lighted, which not only optimizes the utilization of space but also reduces energy consumption and thus the environmental impact. Another advantage of the proximity of school and business lies in the promotion of a better collaboration between the institutions. In addition, this concept can be extended by a large lecture room, which could be used as a cinema and theatre due to its intelligent design, or by the integration of public administration facilities.

**Integrated concept between school, restaurant and residences**

In order to optimize the overall utilization of rooms within buildings in the entire MSP, a concept should be used that offers an overall consideration and unification of the (digitally) re-programmable space approaches of the school, the restaurant and the residential buildings into one overall concept. For such an approach a master booking concept is required. Residents and visitors inform the system about the kind of space they need at a particular time. Based on the requirements of the people and the occupancy, the system automatically assigns the required space within the city to the persons. For example, people can be assigned a workplace or a meeting room in a variety of locations within the city or are advised to stay in their home office due to high occupancy. Therefore, an optimal working environment for people is provided at all times. Moreover, the individual concepts and the overall use of space within the city are further optimized, which in turn intensifies the positive effects in terms of ecology and economy.

### 5.3.2 Approaches of multi-purpose use of public space

The section below provides approaches for the multi-purpose use of public areas within the daily routine. As in Chapter 5.3.1, the concepts are described and the added value is illustrated.

**Community space for multi-purpose use**

According to BOALOTSWE, Botswanan people usually meet with their friends at public places only on weekends, as they usually spend the evenings with their children during the week. Therefore, these places are underutilized from Monday to Friday. At the same time, school areas are only used during the week.[245] This creates a potential for creating a site that can be used for both purposes, which this approach intends. The main requirement is an intelligent design of the site in order to attract people of different age groups and to be suitable for different leisure activities. In this context, the place should serve as a central meeting point within the MSP and has to be close to the school to enable its use as a schoolyard or for sports activities during the week. Furthermore, the integration of a stage on the square would be

[245] cf. Boalotswe 2020

conceivable in order to make it usable for the numerous cultural events, which often take place in open air. In this context, proximity to the restaurant would be desirable in order to provide a combined use of the restaurant and public space for certain events such as weddings. In conclusion, it can be stated that location and design are crucial for such multi-purpose spaces. If these two requirements can be met at the same time, the result is optimized utilization of space that is intended for otherwise less frequently use cases as well as optimized usage during daily routine. This in turn minimizes sealed areas and thus the environmental impact.

**Co-existence of humans and wild animals by digital support**

As already implemented in the synthesis concept and identified as one of the main challenges, solutions have to be found to enable the co-existence of humans and animals in order to predictably prevent human-wildlife conflicts. In order to enable such co-existence, this approach pursues a shared use of land, that is demanded by both, humans and animals. For this purpose, all animal movements have to be monitored. By analyzing the collected data, patterns in the movements of animals can be recognized and times in which no animals are in certain areas can be identified. At this time, the specific area can be used by humans for example as a tourism destination without a direct interaction between animals and humans. However, exceptions within the animal movements can occur, contrary to the identified patterns. Therefore, the system has to check animal movements in real time for potential conflicts. If this is combined with monitoring of people movements – for example via smartphone – potential conflicts can be avoided in advance. As a result, the prevention of human-wildlife conflicts by making space usable for both, humans and animals. By using the mentioned re-programmable space approach property, animals and human life is protected and the co-existence of humans and wildlife is enabled. Furthermore, the use of free areas is optimized without negative affect for animals, resulting in economic and ecological advantages.

### 5.3.3 Approaches of re-programmable options over life-cycle

Besides a multi-purpose use of space within daily life, the (digitally) re-programmable space approach implies the reuse and expandability of space over the life cycle, if space is no longer needed for the original use case or is not sufficient for a further stage of development. The following chapter describes such life cycle re-programmable solutions.

**Extensibility of residential buildings**

According to BOALOTSWE, the culture and life in Botswana implies that children stay on their parent's property with their children and the facilities on this property are extended.[246] Therefore, this approach implies that the smart homes within the living lab have to consider

[246] cf. Boalotswe 2020

expansion possibilities in order to ensure that the residential buildings are usable in line with tradition over their life cycle. For this purpose, the architecture has to be planned intelligently in order to allow house extensions without major structural changes to the existing building structure. Moreover, to ensure the intelligent operation of the building, connections to the new parts of the building have to be considered and the required installations and systems in the house have to be scalable to the further development stages of the house. As a result of this concept, cultural behavior can be maintained by enabling easy and cost-effective extensions of residential buildings.

**Convertibility of floors in residential buildings**

In the previous section, the approach was applied that private houses have to be expandable on the basis of cultural characteristics. However, according to BOALOTSWE, through process of change, nowadays children – especially in cities – sometimes move away from the home of their parents and buy their own property.[247] In such case there would not be too less space available within private homes but too much. Therefore, besides the expandability of residential buildings, an approach for conversion of space within these buildings has to be considered as well. For this purpose, the individual floors should be able to be separated spatially, electronically and mechanically without major structural measures. This enables entire floors to be converted once children move out. Afterwards, these floors can be rented, which provides economic advantages and saves energy costs for the owner. In addition, the utilization of available space is optimized over the life cycle. The described concept can be further extended by conversion possibilities for office space on individual floors.

**Anticipatory re-programming building approach for scaling**

Chapter 5.3.1 described the approach of implementation of a combined area between school and office rooms. This approach is particularly suited to the first development stage of MSP. However, to meet the requirement of scalability, this building has to be adaptable to new development stages, what this approach considers. For this purpose, two solutions exist and can be combined as well. On the one hand, the building design allows an extension of the building without major structural modifications to the existing building structure. This is similar to the approach of the extensibility of residential buildings and thus the same requirements exist. On the other hand, the design of the building can be planned to be adaptable to new framework conditions. This would be the case especially if in the next stage of development only one of the two planned use cases – school or office building – would remain in the building or if both use cases would have to be relocated and the space within the building would be allocated to another use case. In both scenarios, the requirements for the overall space concept would

[247] cf. Boalotswe 2020

change. That is why the existing building structure should be adaptable to new room layouts and use cases. As a result, the described approach enables the building to be easily and cost-effectively adapted to new development stages and thus optimizes space utilization over the life cycle.

**Forward-looking road design**

In order to ensure a mobility concept according to the first stage of development of MSP and to provide scalability of mobility, re-programmable options have to be considered in these infrastructure elements. In this context, focus is on a multi-modal transport concept, as already specified as requirement in the synthesis concept in Chapter 5.2.1. This approach focuses exemplary on the expandability of the traffic concept. Figure 18 shows such an approach.

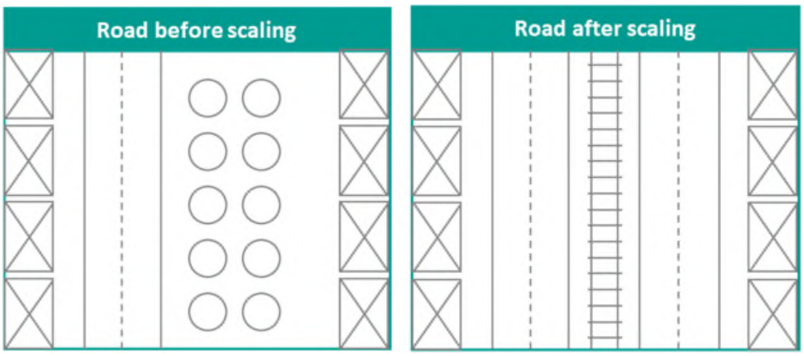


*Figure 18: Exemplary graphic illustrations of forward-looking road design*

As shown in Figure 18, due to its size of the first stage of development, only a road with one lane in each direction is required and within the MSP no public transport can be efficiently implemented – outside the MSP a public connection is conceivable. After scaling, a higher traffic volume is expected and public transport options can also be implemented within the MSP efficiently and cost effectively. Therefore, the space required for the traffic concept after scaling has to be taken into account in the first stage of development in order to avoid major construction modifications to the existing infrastructure. That is why detailed planning and consideration of scaling options are needed. This provides the advantage that transport concepts which should be integrated at a later point can already be developed on greenfield premises in the planning stage. It should be noted that the approach described and illustrated is only a rough example. The approach has to be adapted to the actual developed mobility concept.

### 5.3.4 Extensions to original re-programmable idea

In Sections 5.3.1 to 5.3.3 approaches were discussed, which need to be classified within the original (digitally) re-programmable space idea. In the following chapter two approaches are described, which extend the original idea.

**Multi-purpose use of built-up space**

As already mentioned in Chapter 3.1, the approach of (digitally) re-programmable space implies approaches for multi-purpose use or reuse of space in order to optimize space utilization over the life cycle. However, in order to optimize space utilization and minimize the environmental impact of the infrastructure, built-up areas and thus sealed surfaces should be reduced. Therefore, this concept does not intend to use spaces in buildings for several purposes, but the area built-up by buildings. This means normally additionally required infrastructure is integrated into the buildings for living, business and school – especially with regard to energy, water and food supply. For example, surfaces (roof, wall) of the building are used for heating and power supply through PV and solar technology. Another example is the usage of the roof surface to collect rainwater and the usage of the subsoil underneath the building as a water reservoir by means of a built-in cistern. For instance, this water can then be used to flush toilets or irrigate the garden. Therefore, by generating ideas concerning the described approach, built-up areas are better utilized, sealed areas are reduced and thus the environmental impact is minimized.

**Concept programming in the planning phase**

This concept does not include the original re-programmable approach of space, but rather the programming of the concept and space in a virtual world before the actual physical realization. This means that modern planning technologies – especially Building Information Modeling (BIM) – are used to digitally map all concept components. This results in a digital twin of the MSP within the planning phase already, what allows Botswanans to immerse themselves into the concept by using VR technologies. Thereby they can check the coherence of the concept regarding Botswanan requirements, which optimizes the overall concept. As a result, costly reconstruction measures can be saved in case of errors within the concept. Furthermore, by applying AI technologies, the concept can be simulated before construction is even started. Within this process, AI can simulate different scenarios, whereby the feasibility can be checked and further improvement potentials derived. This approach is interesting, because a digital mapping of the concept within a digital twin is essential for the MSP project, as already discussed in Chapter 5.2.3. Obviously, this digital twin has to be developed already in the planning phase. If this virtual representation is used in the planning phase as mentioned above – by using VR and AI technologies – the concept can be optimized automatically in advance.

### 5.3.5 Requirements of the approaches and identification of necessary IoT solutions

In Chapters 5.3.1 to 5.3.4 the developed approaches for (digitally) re-programmable space were described. In the following Table 4 detailed requirements for the individual approaches are defined and, if necessary, the relevant IoT solutions – sensors and actuators – are derived.

| Approach | Requirements | Necessary IoT solutions (sensors/actuators)[248] |
|---|---|---|
| Multifunctional rooms in residential buildings | - Building operations (e.g. lighting, ventilation, heating, cooling) can be adapted to different types of use<br>- Smart architecture design and interiors enable multi-purpose use<br>- Detailed planning to enable user-friendly switching between use cases<br>- Smart integration into the overall residential building concept | - Sensors for following applications:<br>Motion sensors to identify the activity and condition of people; temperature sensors; oxygen sensors; light sensors; sensors for detecting the position of doors/windows; sensors to detect the incidence of sunlight<br>- Actuators for following applications:<br>Adjustment of ventilation, cooling, lightning and jalousies; if technically possible automatic adjustment of interior<br>→ Adaptation of operations based on sensor data and environmental conditions |
| Restaurant with flexible adaptable room design | - Building operations of each separate room (e.g. lighting, ventilation, heating, cooling) can be adapted to different sizes of groups and use cases<br>- Smart architecture design attracts rooms for different applications and events as well as interiors enable multi-purpose use<br>- Integration of room separation technology to adapt rooms for different use cases and group sizes<br>- Detailed planning to enable user-friendly switching between use cases<br>- Digital booking management system for rooms | - Sensors for following applications:<br>Motion sensors to identify the activity and condition of people as well as the number of people in the room; temperature sensors; oxygen sensors; light sensors; sensors for detecting the position of doors/windows; sensors to detect the incidence of sunlight<br>- Actuators for following applications:<br>Adjustment of ventilation, cooling, lightning and jalousies; if technically possible automatic adjustment of room separation / interior<br>→ Adaptation of operations based on sensor data, environmental conditions and booking information |
| Combined school and office rooms | - Building operations of each separate room (e.g. lighting, ventilation, heating, cooling) can be adapted to different sizes of groups<br>- Smart architecture design attracts rooms for different applications and size of groups as well as interiors enable multi-purpose use<br>- Integration of room separation technology to adapt rooms for different use cases and group sizes<br>- Detailed planning to enable user-friendly switching between use cases<br>- Digital booking management system for rooms | - Sensors for following applications:<br>Motion sensors to identify the activity and condition of people as well as the number of people in the room; temperature sensors; oxygen sensors; light sensors; sensors for detecting the position of doors/windows; sensors to detect the incidence of sunlight<br>- Actuators for following applications:<br>Adjustment of ventilation, cooling, lightning and jalousies; if technically possible automatic adjustment of room separation / interior<br>→ Adaptation of operations based on sensor data, environmental conditions and booking information |

[248] Note: Specific required IoT technologies can only be defined with a detailed planning of actual implementations. Due to the fact that the approaches are at a conceptual stage, Table 4 only gives an overview about the expected applications for sensors and actuators.

| Approach | Requirements | Necessary IoT solutions (sensors/actuators)[249] |
|---|---|---|
| Integrated concept between residences, school and restaurant | - Implementation of a superordinate digital booking system that enables optimized space allocation and usage within the entire MSP<br>- Detailed planning of the rooms in an overall context to provide suitable spaces for all required applications<br>- Requirements of the approaches “multifunctional rooms in residential buildings”, “restaurant with flexible adaptable room design” and “combined school and office rooms” | Necessary IoT solutions of the approaches “multifunctional rooms in residential buildings”, “restaurant with flexible adaptable room design” and “combined school and office rooms” |
| Community space for multi-purpose use | - Smart architecture design and equipment of the site attracts the space for different group sizes, use cases and people of different ages<br>- Furnishing and implemented technologies enable the realization of the Botswanan specific leisure activities and traditional events<br>- Proximity to the school enables use as a schoolyard and school sports activities during the week<br>- Proximity to restaurant allows the use for events in the restaurant<br>- Smart operation of the space (especially lighting) in order to operate only if actually required<br>- Detailed planning to integrate actually required use cases<br>- Practical planning of the allocation of the space or, if appropriate, integration of a digital booking system | - <u>Sensors for following applications:</u><br>Motion sensors to identify the activity of people (use case) as well as the number of people<br>- <u>Actuators for following applications:</u><br>Adjustment of lightning; if technically possible automatic adjustment of furnishing<br>→ Adaptation of operations based on sensor data and if available booking information |
| Co-existence of humans and wild animals by digital support | - Implementation of technologies (sensors) to enable monitoring of animal movements in real time<br>- Detailed mapping and analysis of animal movement with AI within the digital twin in order to recognize patterns<br>- Monitoring of human movements (e.g. via smartphone) in order to provide a real-time warning system for humans to prevent potential human-wildlife conflicts in advance in case of irregularities in animal movements<br>- Providing data to residents to enable them to use the area in the absence of the wildlife | - <u>Sensors for following applications:</u><br>Sensors to identify animal movement (e.g. motion sensors, drones, video tracking; etc.); sensors to identify human movement (e.g. smartphone)<br>- <u>Actuators for following applications:</u><br>Information platform for humans (e.g. via smartphone) to provide instructions about the use of areas and warnings of potential risks<br>→ Information platform is based on analyzed movements within the digital twin |

[249] Note: Specific required IoT technologies can only be defined with a detailed planning of actual implementations. Due to the fact that the approaches are at a conceptual stage, Table 4 only gives an overview about the expected applications for sensors and actuators.

| **Approach** | **Requirements** | **Necessary IoT solutions (sensors/actuators)**[250] |
|---|---|---|
| Extensibility of residential buildings | - Smart architecture enables expansion options without major structural changes to the existing building structure<br>- Building operations (e.g. lighting, ventilation, heating, cooling), installations and systems are upgradeable for a larger building<br>- Installations are smartly connectable to the extension options<br>- Detailed planning including scaling options for further development stages of the building in the context of the overall space needs and the required use cases | This approach is mainly based on architectural requirements and constructional measures; the extension is not convertible with specific applications of IoT. However, it should be ensured that the IoT technologies required for the intelligent control of building operations (see for example the approach "multifunctional rooms in residential buildings") are implemented in the building extensions and that these can be connected to the existing overall building system. |
| Convertibility of floors in residential buildings | - Floors are spatially separable without major structural adjustments to the existing building infrastructure (especially the implementation of separate accessibility of the floors)<br>- Building operations (e.g. lighting, ventilation, heating, cooling) and smart home applications are separable for the floors allowing them to operate independently<br>- Adaptable building operations and smart architectural design enable the conversion of individual rooms to make it possible to use individual floors as fully-fledged apartments<br>- Detailed planning including converting options for further development stages of the building in the context of the overall space needs and the required use cases | This approach is mainly based on architectural requirements and constructional measures; the extension is not convertible with specific applications of IoT. However, it should be ensured that the IoT technologies required for the intelligent control of building operation (see for example the approach "multifunctional rooms in residential buildings") are able to specifically adjust the building operations to the applications on the individual floors in case of a separation of floors. At the same time, the building has to form a well-balanced overall system, even with different applications on the floors. |
| Anticipatory reprogramming building approach for scaling | - Smart architecture enables expansion and converting options without major structural changes to the existing building structure<br>- Building operations (e.g. lighting, ventilation, heating, cooling), installations and systems are upgradeable for a larger building<br>- Installations are smartly connectable to the extension options<br>- Adaptable building operations and smart architectural design facilitate the conversion of individual rooms to enable the usage of rooms for other purposes (e.g. open-plan offices)<br>- Detailed planning including converting and scaling options for further development stages of the building in the context of the overall space needs and the required use cases | This approach is mainly based on architectural requirements and constructional measures; the extension is not convertible with specific applications of IoT. However, the following features should be ensured:<br>- IoT technologies required for the intelligent control of building operations should be implemented in the building extensions and these should be connected to the existing overall building system<br>- IoT technologies that enable intelligent building control should be applicable for other applications within the rooms |

[250] Note: Specific required IoT technologies can only be defined with a detailed planning of actual implementations. Due to the fact that the approaches are at a conceptual stage, Table 4 only gives an overview about the expected applications for sensors and actuators.

| Approach | Requirements | Necessary IoT solutions (sensors/actuators)[251] |
|---|---|---|
| Forward-looking road design | - Smart street and their surrounding design enable expansion options without major structural changes to the existing infrastructure<br>- Consideration of integration possibilities of multi-modal transport options<br>- Detailed and forward-looking planning, as required space and reprogramming activities for growing traffic volume and integration of public transport should already be considered within the first development phase | This approach is mainly based on architectural requirements and constructional measures; the extension is not convertible with specific applications of IoT. However, it should be ensured that the IoT technologies required for the smart mobility control are able to specifically adjust to new framework conditions as well as are implemented in the extension options and that these can be connected to the existing overall mobility system |
| Multi-purpose use of built-up space | - Comprehensive concept that integrates as much of the required infrastructure as possible into the buildings of the daily routine, especially the residential buildings<br>- Use of the built-up area beyond the original intention of usage<br>- Direct integration of Smart City segments within the buildings (e.g. energy production with solar, water collection approaches)<br>- Detailed planning and evaluation of decentralization and centralization of infrastructure assets<br>- Development of an approach in accordance with the Smart Building concept | This approach is mainly based on design and allocation of required infrastructure; the approach is not based on specific applications of IoT solutions. However, it should be ensured that the IoT technologies required for the intelligent control of building operation (see for example the approach "multifunctional rooms in residential buildings") are integrated in the entire infrastructure of the built-up space |
| Concept programming in the planning phase | - Detailed digital representation of the concept and its elements within a digital twin in the planning phase with the help of BIM<br>- Integration of simulation technology based on AI<br>- Use of the digital twin to optimize and evaluate elements of the concept<br>- Interface (VR), which enables people to immerse themselves in the digital concept to get involved and to participate | Exclusively programming the concept in advance of the project implementation does not require IoT solutions. However, by activating the digital twin as the digital representation of the actually implemented project, the application of comprehensive IoT technologies throughout all segments of the Smart City and Smart Buildings is essential, as these serve as the connection between digital and physical world and thus as sensing fabric (for more detailed information see Chapter 3.3 and 5.2.3) |

*Table 4: Requirements and IoT solutions of (digitally) re-programmable space approaches*

[251] Note: Specific required IoT technologies can only be defined with a detailed planning of actual implementations. Due to the fact that the approaches are at a conceptual stage, Table 4 only gives an overview about the expected applications for sensors and actuators.

## 5.4 Added value and critical examination of the overall concept

The final part of the ideation phase of human-centered design is the critical examination. For this purpose, the following section first summarizes the comprehensive added value, afterwards the chapter identifies critical issues within a SWOT analysis and examines the business model of the concept in a Business Model Canvas. Thereby, to proof realizability and practicality, the developed concepts and approaches are regarded and examined in entirety – i.e. the integrated concept including the (digitally) re-programmable space approaches. It should be noted that the three analyses are not exhaustive, individual aspects can always be added in such analyses.

### 5.4.1 Added value

The implementation of the described approaches results in a multitude of added values. These are listed below:

- Smart solutions solve global (infrastructure congestion, climate change, etc.) and local challenges (food/water shortage, human-wildlife conflicts, waste, health, etc.)
- Intelligent solutions improve the life of people, ensure security and privacy as well as protect people's health
- Use of collective intelligence in a collaborative environment enables optimized decision-making processes, enhances problem solving and improves innovative ability
- Availability of comprehensive data based on the sensing fabric within an open data approach enables new opportunities for innovation and continuous improvement
- Real-time data analysis within the digital twin enables continuous optimization of city and building operations, reduces costs, minimizes environmental impact and improves the life of people
- Smart Economy enables the generation of new jobs and business opportunities
- Realization, participation and education leads to upskilling of people, allowing them to participate in a collective smart decision-making process and in a co-creation network
- Optimized production and consumption of resources (e.g. energy, water, etc.) reduces costs and the environmental impact
- Co-existence of humans and animals is possible, which guarantees the safety of both parties and provides the possibility to establish tourism
- Optimized space utilization minimizes the space consumption of the city, reduces the required infrastructure and energy consumption of infrastructure elements – especially buildings – thus saving capital in the construction phase and in building operation as well as optimizing the environmental impact
- Application of a holistic concept as well as intelligent city and building structure enables the creation of a consistent and harmonious urban environment

- Approach optimizes resource utilization, costs and environmental impact over the entire life cycle
- Promotion of the social community through collaboration and participation

Taking everything into account, the mentioned concept improves the life of people, optimizes the city and its operation economically and minimizes the city's environmental impact, thus creating a well-balanced built environment. As a result, the holistic approach serves as a best practice to help Botswana's cities to achieve a successful, healthy and safe future.

### 5.4.2 SWOT

In Chapter 5.4.1 the added values of the concept were already shown. However, to critically examine the concept, risks have to be analyzed in order to counteract them at an early stage as well. For this purpose, a SWOT analysis is applied, which analyzes not only threats but also strengths, opportunities and weaknesses. This is shown in Table 5.

| **Strengths** | **Weaknesses** |
|---|---|
| - Holistic approach considers all identified global (infrastructure congestion, climate change, etc.) and local (food/water shortage, human-wildlife conflicts, waste, etc.) challenges<br>- Intelligent solutions solve complex problems, improve quality of life and help to achieve an economic and ecological successful future<br>- Use of the broad data within the digital twin optimizes resource utilization, minimizes costs and reduces environmental impact over the entire life cycle<br>- Use of collective intelligence based on collaboration and well-founded data increases innovation ability and improves decision making<br>- Providing a well-balanced environment that protects people and their health as well as improves and simplifies their life's<br>- Simulation of the digital twin enables optimization and validation before realization | - Entire concept is difficult to realize due to costs and available technologies. Therefore, a well-founded evaluation is required. In this context, it is only possible to balance the different solution areas if actual implementation possibilities of the individual segments are identified – the concept given in the thesis only provides the overall framework so far. Besides economic affordability, behavioral affordability and accessibility have to be considered as well<br>- Project is difficult to be implemented due to its complex and broad requirements (especially guarantee of real-time data management) |
| **Opportunities** | **Threats** |
| - A well-balanced environment and urban structure can be established through broad citizen participation<br>- Creation of new business opportunities attracts companies and talents from all over the world<br>- Collaboration, co-creation and participation open up new possibilities for collective community | - Concept is only accepted by a minority of the population → resistance because of privacy issues, discussions about data ownership and cultural context<br>- Vulnerability to hacker attacks<br>- Longevity of new intelligent technologies (especially the required IoT solutions) can first be demonstrated in operation → cost risk in the operation phase |

*Table 5: SWOT analysis*

### 5.4.3 Business Model Canvas

Besides general risks, the fundamental business model of new strategies has to be examined in order to ensure a suitable concept for the future. In literature exist a variety of frameworks to analyze business models. One of the most frequently used and in practice proven tools for the evaluation of new strategies is the Osterwalder's Business Model Canvas, which examines the relevant aspects of a business model by separating nine main elements.[252] According to DÍAZ-DÍAZ ET AL., this approach does not suit for the analysis of Smart City strategies, as human benefit has priority over profitability. Therefore, the non-profit approach of the Business Model Canvas is more appropriate, since it takes this aspect into account through the two additional elements "social and environmental benefit" and "social and environmental cost".[253] In the following Table 6, the non-profit Business Model Canvas approach is applied to the concept of MSP.

[252] cf. Díaz-Díaz et al. 2017, p. 200-201; Giourka et al. 2019, p. 5; Osterwalder & Pigneur 2010
[253] cf. Díaz-Díaz et al. 2017, p. 200-201; Osterwalder & Pigneur 2010

<table>
<tr>
<td rowspan="2">Key Partners<br>- Botswana government<br>- District of Maun<br>- Local people and residents of MSP<br>- International cooperation (HTWG Konstanz, TU München, TU Berlin, University Lausanne, University Stockholm, University of Botswana)<br>- Technology and infrastructure providers</td>
<td>Key Activities<br>- Smart Energy<br>- Smart Farming<br>- Smart Water<br>- Smart People<br>- Smart Government<br>- Smart Environment<br>- Smart Living<br>- Smart Economy<br>- Smart Data<br>- Smart Mobility</td>
<td rowspan="2">Value Proposition<br>- Providing smart solutions for global (infrastructure congestion, etc.) and local challenges (food/water shortage, human-wildlife conflicts, waste etc.)<br>- Smart development by the community based on collective intelligence, collaboration and open data approach<br>- Real-time optimization and innovation reliability based on digital twin and sensing fabric<br>- Providing a secure, trusted and supportive physical and digital infrastructure<br>- Providing a safe area for people and their environment<br>- Participation and upskilling based on education and smart tools<br>- Optimized space utilization</td>
<td>Customer Relationship<br>- Collective and collaborative relationship between stakeholders, especially residents, based on trust and education assistance to enable participation and co-creation<br>- Open data approach with anonymization and control options for residents regarding their own data</td>
<td rowspan="2">Customer Segments<br>- Users / residents of Botswana (as best practice)<br>- District of Maun, cities and villages in Botswana as well as government<br>- Local businesses and start-ups</td>
</tr>
<tr>
<td>Key Resources<br>- Local people and residents of MSP<br>- Co-creation network based on collective intelligence<br>- IoT infrastructure / sensing fabric / digital twin<br>- Smart infrastructure and buildings<br>- International cooperation</td>
<td>Channels<br>- Smart collaboration and smart decision network<br>- Smart education and smart data access enable participation e.g. in innovation lab<br>- Transparency through co-creation and open data<br>- Mobile applications for inhabitants</td>
</tr>
<tr>
<td colspan="2">Cost Structure (most important costs)<br>- Infrastructure cost including Smart Buildings<br>- Smart data management infrastructure including required IoT technologies and digital twin<br>- Upskilling/education costs<br>- Costs for smart technologies that meet local and global challenges</td>
<td colspan="3">Revenue Streams<br>- Collective co-creation and innovation ability based on collaboration, open data, collective intelligence and education<br>- Real timed optimization of all operations within the Smart City and the Smart Buildings (e.g. energy) over the entire life cycle<br>- How the city itself generates revenue has to be further investigated (possibilities are taxes, tourism, costs for using the intelligent infrastructure)</td>
</tr>
<tr>
<td colspan="2">Social & Environmental Cost<br>- Potential privacy risks (especially in case of external unauthorized access)<br>- Environmental impact (particularly on animals within MSP) during the construction phase<br>- Difficult for older people to participate, especially due to the poor education of the older generation in Botswana<br>- Possible cultural conflicts → human-centered design can be a key factor</td>
<td colspan="3">Social & Environmental Benefit<br>- Ability to generate new jobs and business opportunities through smart economy<br>- Optimized consumption, services and space utilization improves resource consumption, costs and environmental impact<br>- Application of a holistic concept enables the protection of people, improves health and life, attracts tourism and creates a consistent environment<br>- For a more detailed overview see Chapter 5.4.1</td>
</tr>
</table>

*Table 6: Business Model Canvas Maun Science Park*

# 6 Conclusion and recommendation for action

In the following last chapter, the objectives of the thesis presented in the introduction are discussed. After the summary of the most important aspects, the guidance for further proceedings is established. In this context, the chapter serves as the third phase of human-centered design – the implementation phase.

Through the theoretical foundations of Smart City and Smart Building, including general reference projects as well as relevant aspects relating to the approaches, combined with Botswanan challenges and requirements, a synthesis concept specifically for the MSP has been developed based on an MSP framework. The holistic approach manages the identified requirements and challenges by providing solution areas for the Smart City MSP (ten main segments, 37 sub-segments) as well as for the Smart Buildings (three main segments, 16 sub-segments). Thereby, the concept shows requirements of each individual sub-segment which should be considered in the further course of the project and thus serve as an overall concept as well as an important requirement definition for the further development of MSP and its segments. As a result, the developed synthesis concept can serve as best practice approach for future urban development in Botswana within the 4IR strategy.

A prioritization of the sub-segments was required, as a complete implementation of the concept might not be practicable due to technological and financial possibilities. For this purpose, a qualitative comparison of the economic affordability and impact of the individual areas was applied. Segments within Quadrant I (see Figure 13 and Figure 15) are to be considered with highest priority, respecting the important elements identified in Chapter 5.2.3. Since the analysis is only a qualitative evaluation, the identified solution areas should be combined with specific solutions in the next project steps in order to quantify them. The established synthesis concept and evaluation in this thesis can serve as a reference point. Furthermore, for prioritization, the criteria accessibility and behavior affordability should be taken into account, since these are significantly relevant due to the boundary conditions in Botswana. An overall assessment, for example by indexing, would be desirable. Based on these results, it could be defined which of the solution areas are to be pursued with highest priority in the further project steps.

Within Chapter 5.2.3 the most important superordinate contents of the concept were summarized, which are based on the defined interactions within Smart City and Smart Building segments as well as the expert input of HERO. These are particularly related to the segments Smart Data and Smart People, which therefore have to be considered in a prioritization. In addition, this part determined that a combination of the Smart City 2.0 and 3.0 development phases should be pursued in the next project phases.

Moreover, the thesis presents various implementation possibilities for approaches of (digitally) re-programmable space, indicating the optimized use of the available space over the life cycle and the different MSP stages. In this context, besides ten conventional approaches – multi-purpose or reuse options – two suggestions have been created, which extend the conventional (digitally) re-programmable space concept – “multi-purpose use of built-up space” and “concept programming in the planning phase”. Each of the twelve identified approaches offer extensive advantages, which have been described in Chapters 5.3.1 to 5.3.4. In addition, requirements for the individual concepts have been formulated and, if necessary, the required IoT technologies have been defined. In the next project steps, it should be analyzed and examined in detail to which extend the approaches can be applied within the MSP infrastructure in order to optimize the space use over the life cycle and thus minimize the environmental impact.

In an overall review it has been shown that by implementing the holistic approaches a successful economic future is created, innovations are promoted through collaboration, co-creation and collective intelligence, social community and the life of people is improved as well as the impact on the environment is minimized. This is achieved by focusing on the human being within the development process. Additionally, the business model was critically tested within a Business Model Canvas which demonstrated the benefits and functionality of the concept.

Besides the benefits and added value of the developed concepts, weaknesses and risks were identified as well. These are particularly related to the technological feasibility and the readiness of people. Consequently, in the next project steps the cooperation with experienced universities and firms has to be intensified in order to ensure the availability of the required technologies, to define a detailed realizable concept with solutions based on the synthesis concept as well as to secure the functionality – especially of data management – in the operating phase. Furthermore, the exchange with the population has to be enhanced to innovate along their requirements. In this context, it is essential that educational programs in the planning phase outline the comprehensive added value of MSP to the population and transfer the contents to enable them to participate in the development process. Thereby, a proactive and open discussion regarding privacy and data ownership with the public is required in order to implement appropriate solutions and to prevent possible resistances at an early stage. In order to promote participation and transparency, the (digitally) re-programmable space approach "concept programming in the planning phase" (see Chapter 5.3.4) can assume a key role. Programming the digital twin at an early stage enables the population to immerse themselves digitally in the concept through VR. In this process, they can compare the concept and their elements with their requirements and lifestyle, thus proactively introducing improvement suggestions into the development process. In this way, undesirable developments and investments can be avoided.

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## Statutory declaration

**Hochschule Konstanz**
Department of Civil Engineering

**Appendix to the Master Thesis of**

Felix Lay

**Statutory declaration**

I hereby declare in lieu of oath that I have independently completed the above-mentioned master thesis and have completely specified the resources used as well as the persons and institutions interviewed.

Konstanz, 02.11.2020 [redacted]

## Appendix