

# The Social Digital Twin: The Social Turn in the Field of Smart Cities

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## Abstract

Complexity theory has become a conceptual framework and a source of inspiration for Smart City initiatives. In addition to many other conceptions, the Urban Digital Twin (UDT) became both a concept and a tool for generating the revolutionary act of data-driven 3D city modeling. Indeed, the UDT has increased the ability of planners to make decisions vis-à-vis data-driven city models; at the same time, however, it has attracted criticism because of its focus on the physical dimensions of cities. In facing these challenges, we seek to join the conceptual and practical efforts to generate a *social turn* in the field of Smart Cities and urban innovation. Creating a UDT with a social focus, we maintain, is not only a 1:1 translation of the built environment into the social realm, but also demands interdisciplinary knowledge from the fields of sociology, anthropology, planning, and ethics studies. This article makes theoretical and methodological contributions. **Theoretically**, it discusses the potential contribution of the Social Urban Digital Twin (SUDT) to the theory of urbanism, enabling us to represent the physical and the social environments as a single fabric. **Methodologically**, it enhances the know-how of the City Analytics research community by advancing a six-phase protocol for developing SUDTs, each phase of which integrates technological conceptions and social-theoretical content. The phases of the SUDT protocol are demonstrated using a specific case study: the experience of elderly residents of the Haifa neighborhood of Hadar—a low-income neighborhood in Israel characterized by ethnic and national diversity—during the Coronavirus pandemic. We conclude by discussing the contributions and limitations of the SUDT.

## Keywords

Digital twin, social planning, urban complexity, urbanism, social turn in the field of smart cities

## Prologue

This study took form during the outbreak of the Coronavirus pandemic of 2020–21, in which the age-old practices of quarantine and social distancing were employed as means of halting the spread

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of the virus. Prior to the pandemic, the goal of the study was to produce an administrative and planning solution for elderly residents of the neighborhood of Hadar in Haifa, Israel. The more the virus spread, the worse the situation of the elderly population in general, and in the neighborhood of Hadar in particular, became. During Israel's second lockdown, 14 elderly residents died alone in their apartments, and their bodies were found in an advanced stage of decay only a few days later (data source: ZAKA-Israeli NGO rescue units). It was a meaningful moment for the development of our research. This was a new and unusual phenomenon for Israeli society that put the Municipality of Haifa in an uncomfortable and helpless position, raising the question: How could such a thing happen in a city like Haifa, which is ranked 24 on the list of the world's Smart Cities (according to the IESE Cities in Motion Index, 2014 (Aharon-Gutman et al., 2018))? For us, it was a result of the lack of an effective social and administrative response to social issues within the conception of the Smart City (Kitchin, 2014; Sadowski and Bendor, 2019).

## Introduction

In this article, we propose the Social Urban Digital Twin (SUDT) as a conceptual framework for incorporating social aspects into the decision-making process. The SUDT imbricates with the development and maturation of the Urban Digital Twin (UTD), which is associated with the ideas, logics, and practices of Smart City conceptions and technology (Batty, 2018; Shahat et al., 2021). The UTD model is viewed as the holy grail of Smart City technologies (Deren et al., 2021; Ruohomaki et al., 2018), serving as a means of collecting and integrating city data that is streamed in real time from physical devices connected to information and communications technology (ICT) and grounding it in a 3D model of physical space. The SUDT encodes methods from the UTD and expands them with sociological approaches, such as focusing on social issues like urban aging and gentrification, and integrating social fabric and the built urban environment. This, we hold, is reflective of a new socio-technical imaginary in the social turn of Smart Cities (Jasanoff and Kim, 2015; Sadowski and Bendor, 2019).

As with every social phenomenon, this study also had a contextual system that produced unique conditions for the growth of the idea of the SUDT. These contexts differ fundamentally from the conditions surrounding the development of previous Smart City technologies, including that of the UTD. The SUDT concept was developed as part of an applied research grant provided by the National Insurance Institute of Israel and in cooperation with local communities and with Haifa's municipal Department of Welfare. In other words, the SUDT was developed by a technological-academic research institute using social-institutional funding and is therefore not subject to the logics of the neoliberal corporate economy (Cardullo and Kitchin, 2019; Harvey, 2003). Another difference between the environments in which Smart City technologies are typically developed and development of the SUDT lies in the case study and the geographical scale used. Commitment to the neighborhood scale in a locality characterized by ethnic mixing, low socioeconomic ranking, and a high percentage of elderly residents made engagement with the social fundamental to the project: that is, it is abundantly evident that this neighborhood cannot be understood without understanding poverty, old age, social disparities, etc. Another important contextual system was provided by the Coronavirus pandemic: the development of the SUDT began just moments before the pandemic and reached its height during the crisis itself. This period highlighted the importance of the social dimension in urban management during an epidemic and bolstered our motivation to engage in the social content world. Indeed, we maintain that the SUDT constitutes not only an act of translation between disciplines, but rather also a new conceptual idea that poses new questions and challenges regarding ethics and regulation, models of cooperative development, and power relations.

This article makes theoretical and methodological contributions. **Theoretically**, it discusses the SUDT's potential contribution to the theory of urbanism, enabling us to represent the physical and

the social environments as a single fabric. **Methodologically**, it enhances the know-how of the city analytics research community by advancing a six-phase protocol for developing the SUDT, each phase of which integrates technological conceptions and social-theoretical content.

In section one, we present the concept of the SUDT and its contribution to the theory of urbanism. Section two takes a look at the neighborhood of Hadar as a case study, with a focus on its elderly citizens during the Coronavirus pandemic. Section three constitutes the core of the study, with its formulation of the SUDT protocol as a tool for a social turn in Smart Cities. The proposed six-phase generic protocol can be applied to a wide variety of places and social issues. In this section, we demonstrate their application within our specific case study and show how the protocol sheds new light on the work of the municipal Welfare Department and civil society. The paper concludes with a summation of the process, its potential, and the conflicts it poses, and proposes follow-up studies for expanding the boundaries of the development of the SUDT.

### *Section 1: From UDT to SUDT: The social Turn in the field of Smart Cities*

Over the past few years, projects from the field of Smart Cities have come under substantial criticism for focusing too heavily on technological development that can enable the city to manage urban crises (Cardullo, 2020; Nochta et al., 2020; Verrest and Pfeffer, 2018). This criticism comes in response to the lack of socio-technological applications aimed at assisting with and solving problems within urban systems (Cardullo and Kitchin, 2019; Sadowski and Bendor, 2019). In light of this criticism, Smart City technology companies have started to brand themselves as “social companies” while simultaneously meeting the neoliberal economic corporate conditions of profit and power relations (Harvey, 2003; Kitchin, 2013). Developments that have been portrayed as “social” because they reduce the communication between city residents and mayors, have intensified this criticism in light of the corporate dominance in building conceptions and tools, which has allowed corporate interests to seep into the social realm. The result has been a socio-technical imagination that has appropriated smart urbanism, established its status using the narrative of the urban crisis and technological redemption, and assimilated the social into sellable templates. Researchers have called for a counter-narrative to facilitate alternative social representation (Sadowski and Bendor, 2019 p.557). The absence of social perspectives in the realm of Smart Cities has resulted in immense disparity in the economic development and social resilience of different cities, and the outcomes constitute the main social challenges of our time: displacement, gentrification, and spatial inequality. These phenomena have emerged due to technological gaps between the welfare departments and the economic departments of cities, among other things.

Our research focuses on the UDT model, which is regarded as an essential tool for Smart City technologies (Ruohomaki et al., 2018). The roots of the development of the UDT lie in the processes of digital twin product design and production—that is, in the replication of physical consumer products within a virtual system that allows optimal symbolization and planning of the product or the production line (Grieves and Vickers, 2017; Singh et al., 2021). Over the past decade, the digital twin has also gradually developed into the urban field, producing a “virtual copy” of urban physical space (Batty, 2020; Shahat et al., 2021). The UDT links 3D models to urban data by feeding data from throughout the city into the UDT to provide an effective way of contemplating, recognizing, and controlling physical space. In many cases, the data that is fed into the UDT is generated by a variety of devices and means associated with Smart City technologies (Deren et al., 2021). Sensors, cameras, and smart technical infrastructures produced by Information and Communication Technology (ICT) and the Internet of Things (IoT) are integrated into the UDT datasets model, facilitating the creation of a multidisciplinary and multilayer image of the city (Batty, 2018). The UDT’s unique form allows the research, simulation, and testing of new design ideas for the city, the main goal of which is to improve the city system itself. Batty (2018) argues that UDTs are similar to

a computer model and are limited in the variables and processes they can manage. Therefore, typical UDTs deal with a specific topic or issue, such as planning (Schrotter and Hürzeler, 2020), sustainability (Dembski et al., 2020), or disaster management (Fan et al., 2021), to name just a few.

We are critical of the UDT as a tool that portrays primarily the physical environment of the city and that has almost completely ignored the city's social fabric. Smart Urbanism addresses this lacuna by adding the aspects of city technology to the ideas of urbanism (Verrest and Pfeffer, 2018). The theory of urbanism, which emerged from the field of urban studies, focuses on incorporating the physical and the social environments into a single fabric. In other words, it seeks not to focus on the *urb* (Latin: a city surrounded by wall, symbolizing the physical realm of cities) or the *urbanus* (Latin: the devotion or sense of belonging to a city, symbolizing the social realm of the city), but rather to face the challenge of urbanism—the relations between the two. In response to this challenge, Smart Urbanism proposes “citizen-centric” as a method of integrating the social fabric and the physical environment (Cardullo and Kitchin, 2019).

Researchers from the fields of Social GIS and Critical GIS have responded to this challenge with the argument that cartographic transformations using the tool of Geographic Information Systems (GIS) have the potential to bring about social change (Ballas et al., 2018; Pavlovskaya, 2018). These movements have called for adopting the methodology of GIS mapping technology, which is typically associated with the forces of progressive development and managed by economic corporations; they have also advocated change in fields of knowledge and methods of mapping to promote values and social issues that have been sidelined or have vanished from the public discourse.

In this study, we ask how the progressive development of Smart City technologies can be expanded by critical thinking in the social sciences, by doing that we hope will minimize the digital gap (Graham, 2002) between the municipal welfare departments and the conception of Smart City management.

## Section 2: The case study: the neighborhood of Hadar in Haifa

Our case study focuses on the neighborhood of Hadar in Haifa, Israel's third largest city. A port city with a long history, Haifa is home to a mixed population of Arabs and Jews. Today, Hadar has a population of 43,413 (according to the National Insurance Institute of Israel) living in 14 different statistical areas covering a total area of 2.83 square kilometers. Hadar was founded in 1922 on the mountainous slopes of Mt. Carmel, which required building within a complex topography (Fisher, 2014) and a building typology of three-to-four stories, with no elevator. At first, the neighborhood experienced a golden age during which cultural institutions and public buildings were built and the population was largely middle to upper class. Since the beginning of the 1970s, however, Hadar has experienced a process of social and physical decline (Shilo, 2018). During the mass Jewish immigration to Israel from the former Soviet Union in the 1990s, apartments in Hadar that had long stood empty were populated by new immigrants seeking inexpensive housing solutions (Komemi and Yavelberg, 2015). This period also witnessed the onset of the phenomenon of apartments being split into smaller apartments to maximize rental profits.

In the context of the city's elderly population, Hadar is an aging neighborhood, with 16.7% of its residents over the age of 65, in comparison to a national average of 12%. Fifty-eight percent of the neighborhood's 65+ population are either single, widowed, or divorced, in comparison to a national average of 40%. This indicates that the elderly residents of Hadar have a higher risk of living in solitude than Israel's overall elderly population.

Engaging the issue of the elderly during the Coronavirus pandemic sheds light on new challenges to the neighborhood. The elderly residents who live alone and in poverty found themselves in extreme situations due to the “social distancing” requirement, which became a necessary condition

for preventing and limiting Coronavirus infection. As a result, the first and second lockdowns witnessed the death of 14 lone elderly residents, whose bodies were only found in their homes a few days later (data source: [ZAKA](#)).

### Section 3: SUDT protocol implementation

In this section, we propose a six-phase protocol for producing a SUDT. Each phase is based on both technological conceptions and sociological contents ([Table 1](#)). For each phase, we explain the conception we developed and the action required, with the intention of formulating a generic protocol that can be applied to a wide variety of places and issues in the urban world. We also explain how we implemented each phase in the context of Hadar. Here, we work within the tension between local and generic knowledge by first responding to the international research community and then giving back to the local forces that are our partners in the process.

#### Phase 1: 3D city digital model

A SUDT creates a mirror image of the environment in virtual space ([Batty, 2018](#); [Grieves and Vickers, 2017](#)). Therefore, the production of many UDTs has begun with a visual representation of

**Table 1.** Phases of the development of the SUDT protocol. Each phase is based on unique technological conceptions and social-theoretical content.

Phase of Social Urban Digital Twin Protocol	Technological Conception	Social-Theoretical Content	Description of Phase
 Phase 1 3D City Digital Model	3D city visualization	—	3D virtual representation of the urban environment
 Phase 2 The Ethics of Social Data	—	The data ethics of digital sociology	Regulatory and legal measures to facilitate social data collection
 Phase 3 Data Collection through Thick Mapping	Collection of various datasets	Thick mapping as a tool for utilizing social complexity	Thick description of Institutional and civic data collection
 Phase 4 “Small-ness” Data Integration large table	Feature Scaling and integration into one	The “small-ness” urban scale and the household unite	Combination and integration of data into a single array on the household scale
 Phase 5 Socio-Spatial Visual Dimension geographical data	Integration of “classical” tabular data into	Social GIS as a link between environment and society	Use of spatial visualization platform for analysis and to generate social insights
 Phase 6 Critical Algorithm Correlation	Correlation and algorithm analysis of data	Critical thinking through data analysis by social-spatial visualization	Use of algorithms to integrate information from different sources to generate insights

the physical space within the virtual realm through the creation of 3D models of the city based on CAD design technology or VRML (Virtual Reality Modeling Language) (Levine et al., 2021). The 3D city model has made history as a tool for generating discussion and producing city strategy (Toland and Kilbane, 2018). Today, in the digital age, the 3D city model has assumed a new, virtual configuration, and its physical materiality has been replaced by multi-scale and multi-view photo-geometric technology, enabling it to be both dynamic and integrative (Shirowzhan et al., 2020). Therefore, the production of an SUDT begins with the creation of a 3D mirror image, in virtual space, of the built physical realm. There are many methods for creating 3D city models, from commercial companies, to open-sourced platforms such as OSM, to the use of drones with integrated cameras that produce completely automated real 3D models.

**In Our Case:** We used two languages (vector and hyper-realistic) to achieve the 3D representation of the Hadar neighborhood (Figure 1). A vector-based language incorporated into the SUDT makes use of the CAD model at a detail level of LOD 2.3 (building footprint extension) and includes a vector-based abstraction of the urban buildings (Biljecki et al., 2016). The model was acquired from Systematics ([www.systematics.co.il](http://www.systematics.co.il)), a company that produces this layer of buildings based on aerial photographs; it includes a layer of metadata pertaining to the date of construction, the height of the building, and the number of stories. A layer generated by hyper-realistic language based on the technological design of VRML was acquired from Simplex ([www.simplex-mapping.com](http://www.simplex-mapping.com)), a company that produces a 3D mash layer using aerial photography that scans a specific space and translates it into a 3D model using a system of onboard processing algorithms. Simplex's hyper-realistic model has a resolution of 3 cm per pixel and is grounded in GIS. This language of representation seeks to create an exact visual reproduction of the physical space as it is. As a result, it is rich in detail and urban texture, which eases orientation in the virtual urban space.

### *Phase 2: The ethics of social data*

Whereas the first phase of the SUDT model presented above is a generic phase of UDT development, the second phase marks a turning point – from a focus on built urban space to a focus on social fabric. This turn requires adaptation and raises ethical and legal questions that are very popular in the field of Digital Sociology (Lupton and Deborah, 2015). The SUDT model offers a solution for contending with social issues and therefore requires a process of collecting and assimilating social data. A broad spectrum of laws and regulations were instituted to protect the privacy of the population. Producing the SUDT requires learning the laws of the public sector



**Figure 1.** Two languages of 3D model representation of the physical environment. Left: Hyperrealism Model by Simplex. Right: Vector Spatial Model by Systematics.

throughout the country and signing the necessary contracts. Therefore, before getting underway with socially focused research, it is necessary to first build an institutional support structure consisting of an attorney and the Cyber Director of the relevant organization to assist in creating a legal and contractual basis for receiving the data.

**In Our Case:** The sensitive social data we received from the Municipality of Haifa to build the SUDT included information regarding all the households in Hadar. Prior to beginning the development, we signed a legal agreement facilitating the transfer of information from a public institution to academia. In the agreement, we were required to specify how the information would be stored and secured. We also signed a contract obligating us to meet the conditions of privacy protection law. To this end, it was decided that all the social data we received would undergo anonymization before reaching us and would contain no identifying information of the residents (such as national ID number). It was also decided in advance that the information would be stored within the Technion's server system. Creating the SUDT involved working with the organization's academic legal advisor and cyber-expert, who together provided us with professional support and a solution for communication with City Hall. Furthermore, the protocol of our study was approved by the Ethics Committee of an internal committee of the Technion.

### *Phase 3: Data collecting through Thick mapping*

Data is not single-use and is not one dimensional. The essence of the Digital Twin lies in its ability to incorporate substantial changing data to serve as a foundation for conducting analyses and generating insights (Kenett and Bortman, 2021). The SUDT relates to data as an epistemological means of reflecting a narrative that differs from reality. Social data can come from institutional and non-institutional bodies, and understanding social complexity necessitates viewing it from different perspectives and on different scales (Aureli and Schino, 2019). For this reason, we propose the concept of "thick description" (Geertz, 1973) a methodology from the field of Cultural Anthropology, as a method of data collection. Thick description refers to a process by which the neighborhood is documented in a "thick" manner (i.e. data is collected, accrued, and presented in a holistic manner that enables us to learn about the neighborhood and about a broad spectrum of subjects). The idea behind the SUDT is not to collect data pertaining only to specific questions selected ahead of time, but rather to open up the data-collection process to broader contexts.

Thick description is the basis of critical thinking, as it provides researchers with a wide cultural and political contextual framework in which to analyze phenomena and narratives (Presner et al., 2014). It can be used to highlight and conduct a combination of micro and macro analyses with multiple interpretations and to tell open stories that do not reflect a single worldview. To establish and expand the idea of creating multiple narratives, we propose filling out the institutional database with data that is generated not only from the top down but also from the bottom up.

**In Our Case:** The process of producing a "thick description" of the social realm of the neighborhood was based on three primary sources of information. Two of these sources—central government agencies and the Municipality of Haifa—provided data that was generated from the top down. The third source—civil society in the neighborhood of Hadar—provided data generated from the bottom up. The connection between multiple sources of information and movement among different data reflecting different perspectives enabled a better understanding of phenomena within complex social contexts and ensured critical thinking within the project. Table 2 presents a list of database resources, file formats, and data scales.

*Top-Down Data: Institutional Data:* Israeli Government Decision 1933 from 2016 resolved to create a government database that is open to the public in order to increase accessibility and increase innovation in the public sector and the public services. The lowest-resolution geographical information that appears on the open government information site pertains to the level of the statistical

**Table 2.** Social digital twin database.

	Organizations	Topic	Data Type	Scale	File Type	
Institutional Data	Ministry of Transportation	Public transportation	Bus lines	City of Haifa	SHAPE	
			Bus stops	City of Haifa	SHAPE	
	Ministry of Health	Coronavirus infections	Age	City of Haifa	SHAPE	
			Gender	Statistical area	Excel	
	Survey of Israel	Geographic information	Topography	Statistical area	Excel	
			Land use	City of Haifa	SHAPE	
			Blocks and plots	Statistical area	SHAPE	
	National Insurance Institute	Demography	Street names	Statistical area	SHAPE	
			Gender	City of Haifa	SHAPE	
			Number of residents			
		Financial assistance	Age 0-17, 18-34, 35-44, 45-54,55-64,65-74,75-84, 85+	Statistical area	Excel	
			Income guarantee recipients	Statistical area	Excel	
			Senior citizen pension	Statistical area	Excel	
			Disability fund	Statistical area	Excel	
			Nursing allowance	Statistical area	Excel	
			Marital Status	Widow/widower	Statistical area	Excel
				Divorcee	Statistical area	Excel
	Haifa Municipality	Property tax	Married	Statistical area	Excel	
			Unmarried	Statistical area	Excel	
			Assets file	Statistical area	Excel	
			Number of persons per	street name and address	Excel	
			Apartment area	street name and address	Excel	
			Age of property owner	street name and address	Excel	
			Rental / Ownership	street name and address	Excel	
			Type of tax rebate	street name and address	Excel	
			Engineering-GIS	Public parks	street name and address	Excel
				Pharmacies	street name and address	SHAPE
Public libraries		street name and address		SHAPE		
Sports fields		street name and address		SHAPE		
Department of Welfare		Exercise machines	Exercise machines	street name and address	SHAPE	
			Community centers	street name and address	SHAPE	
	Recycling points	Recycling points	street name and address	SHAPE		
		Elderly citizens under care of Department of Welfare	street name and address	Excel		
	Residences of Holocaust	street name and address	Excel			
	locations of senior citizen	street name and address	Excel			
	addresses of senior citizen	street name and address	Excel			
	106 Hotline	Inquiries received from the neighborhood between 2019	street name and address	Excel		
	Civic Data	Shahaf Foundation	Location of intentional	Names of the communities	street name and address	Excel
			Addresses of "building"	Building address	street name and address	Excel
Food parcel distribution			Building address	street name and address	Excel	

area, which is home to between 3000 and 5000 residents, and therefore does not allow individual identification. For example, we incorporated data regarding transportation, bus stop locations, and bus routes.

The health-related data pertained to Coronavirus on the level of the statistical area. This dataset contains quantitative data regarding the number of those infected and those recovering broken down by age and statistical area. The data is updated on a daily basis, and we therefore wrote scripts to access this data and update the SUDT in real time.

From the Survey of Israel, we drew information pertaining to the physical and planning aspects of the neighborhood of Hadar. From this dataset, we incorporated information regarding topography, land-use designation, blocs and plots, and street names.

The National Insurance Institute of Israel is the state body responsible for facilitating the enactment of the social rights of all inhabitants of the state through financial payments. As a result, this agency possesses extremely detailed social information on all Israeli residents. As part of our research cooperation with this project, the National Insurance Institute provided us with absolute information on the level of the statistical area, including the number of inhabitants, a breakdown by age group, a breakdown by family status, and information regarding financial benefits.

The Municipality of Haifa provided us with a file on local property tax in the form of an Excel table with 22,000 rows, each representing a household in the neighborhood. The table contained the following columns: property type (residential or commercial), property area, age of property holder, and tax discount applied. This information enabled us to characterize the social and economic situation of the neighborhood's residents. The city hotline provided us with a file documenting calls going back one year; the file contained the address at which the hazard occurred, a categorical description of the type of hazard, and a verbal description. The municipality's Culture and Community Department assisted us in generating data regarding social volunteers and activists.

Bottom-up Data: Civic Data: Three datasets that were produced by various civic bodies provided us with snapshots of the civic condition of the neighborhood's elderly residents:

1. A food basket distribution dataset, containing the addresses of elderly residents who received a food basket during the second Coronavirus lockdown: This distribution was conducted by civil society organizations seeking to help elderly residents who typically visit food basket distribution points but who were now refraining from leaving their homes out of fear of being infected by the virus.
2. A building coordinators' dataset, which provided us with information about building maintenance: Buildings with a building coordinator had maintenance costs that are higher than buildings without a building coordinator.
3. The addresses of community members: Our study collaborated with the Shahaf Foundation, a philanthropic organization that offers financial support to local communities in Hadar that provided a list of all their communities' members in the neighborhood.

#### *Phase 4: The "small-ness" of data integration*

This is a complex phase, because it demands a process of dismantling and assembling the array of data that was collected during the previous phase and creating a new dataset. In this phase, we ask how integration and unification can be achieved among the data arriving from different information sources, and, in the process, also in different formats and on different urban scales (statistical areas as opposed to addresses). In the field of data science, this complex issue is known as "feature scaling," and its goal is to achieve the standardization and normalization of datasets. To achieve optimal feature scaling, we use principles and concepts from the field of urban sociology, which proposes the concept of "small-ness" and a shift to small urban scales as a means of critically

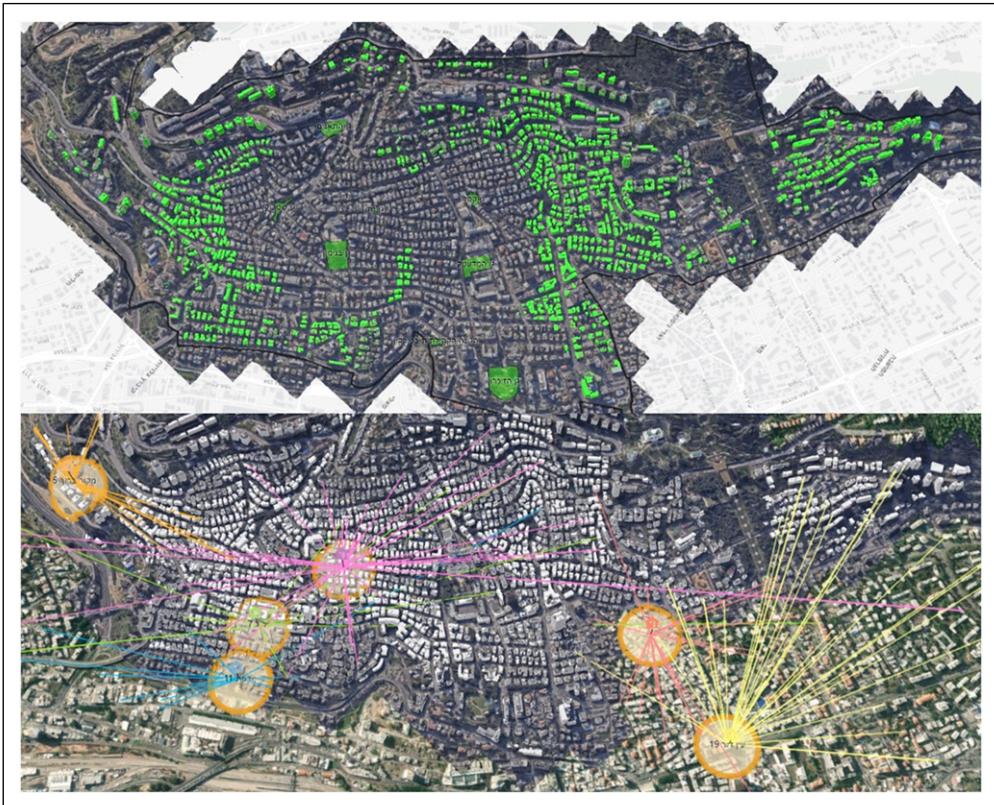
analyzing urban complexity (Ocejo et al., 2020). In this spirit, we recommend that the SUDT dataset preserve the smallest urban unit that exists in the dataset.

**In Our Case:** The dataset consisted of information on the scale of the city, the statistical area, the address, and the household. In this context, too, we employed analyses and concepts from the content world of urban sociology, which relates to the residential unit of the household as the true building blocks of society and the outcome of economic and social development (Puschmann and Solli, 2014). In a more concrete manner, we constructed one large table consisting of 22,000 rows, each representing a single household, and more than 100 columns, each representing a social dataset that was translated from verbal descriptive data into data with a rational numerical value.

### *Phase 5: The socio-spatial visual dimension*

This phase's goal is to use spatial visualization and analysis to generate social insights and create a logical context linking geographical space and social complexity (Aharon-Gutman et al., 2018; Ballas et al., 2018). In this phase, we structured "classic" tabular data into geographical-data descriptions of points, lines, and polygons, using methods and techniques from Social GIS to create visual representations of the elements of the social data.

**In Our Case:** We generated many different kinds of spatial analyses and insights, with the thrust of our methodology based on the production of social information and insights through cross-



**Figure 2.** Social Digital Twin model visualization. Top: Visualized in green. Elderly households located more than 250 meters away from local parks. Bottom: Spatial distribution of adult daycare centers in relation to home addresses of members.

checking different kinds of sources of social information and spatial analyses. Here, due to limited space, we expand on only two of these analyses (Figure 2):

1. The distance of the elderly resident's residence from points of interest: The goal of this analysis was to assess the extent to which public functions are accessible or inaccessible for the elderly residents of the neighborhood. According to a study of the "age-friendly city" (Kano et al., 2018), optimal mobility of elderly residents in public space requires them to live within 250 m of accessible functions such as a bus stop, a medical clinic, a post office, a public park, and a grocery store.

We selected the entire elderly population (65+) from the local property tax file and marked the buildings in the neighborhood in which they lived. We then marked the location of the relevant public functions using open street mapping. Next, we formulated a spatial query for a 250-m-long spatial buffer around the social function in question, and on the map we marked the elderly residents who do not live near it.

2. The spatial distribution of adult daycare centers in relation to the home addresses of center members: The aim of this analysis was first to view the spatial distribution of adult daycare centers that the Welfare Department provides as a service for elderly residents, and then to establish the geographical relationship between center members and the center's location. From the analysis, we learned that the adult daycare centers were not distributed evenly across the neighborhood's geographical space. We also discovered that most of the elderly residents did not live within walking distance of the center and therefore needed to be driven there.

### Phase 6: Critical algorithmic correlation

This stage has extended the fundamental concept of Digital Twin technology, mixing different kinds of data to facilitate correlation and coordination for producing data insights (Grieves and Vickers, 2017) and using critical thinking and social-geospatial layers to extract social insights. In this phase, we propose analyze the relationships between a discrete quantitative variable and other variables using algorithmic analysis of the social dataset (produced in Phase 4 of the protocol). In addition, to implement the concept of the SUDT, which links the social fabric and the physical built fabric, we produce social-geospatial layers that enable us to critically analyze the result of the algorithmic

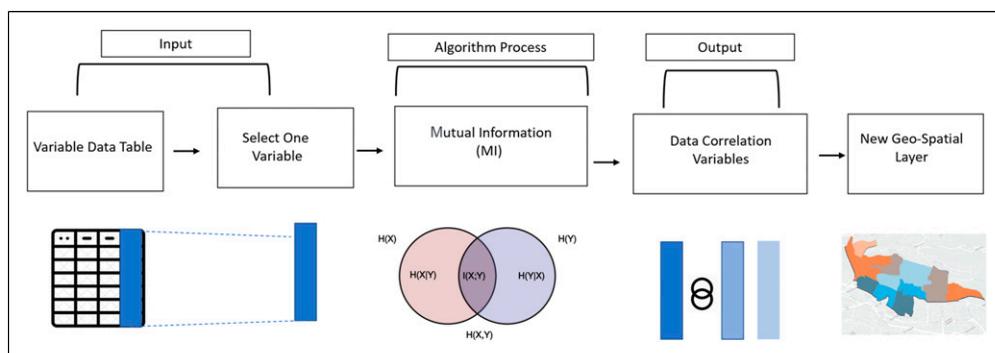


Figure 3. The four stages of implementing the algorithm.

analysis in relation to the built environment. This phase is composed of four stages (Figure 3): (1) The input stage, in which a single variable is selected from the entire data set. (2) The algorithm process stage, in which we propose using the generic algorithm of mutual information, which assesses the mutual dependence of two discrete variables. (3) The output stage, in which we use the algorithm to display the two variables with the highest percentages of similarity to the variable we selected in the input stage. And (4) the geospatial layer stage, which produces a new geospatial layer displaying the two variables with the highest percentage of similarity identified by the algorithm. This layer actually represents the spatial-social relationship between the two variables, enabling critical thinking data analysis.

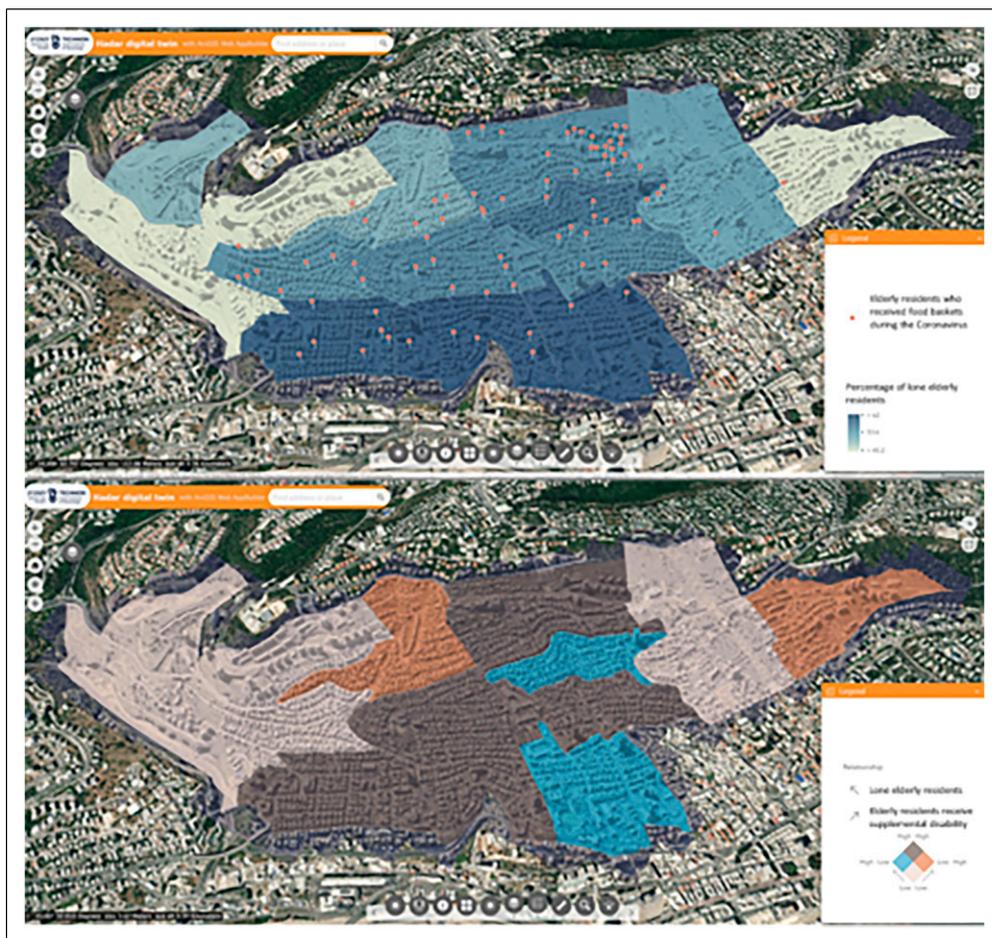
**In Our Case:** In the course of the development of the SUDT, we applied this phase of the protocol individually to different discrete variables, each of which we selected in dialogue with one of our partners. Due to our inability to expand on this in detail here, below we present a simulation, reflecting the application of this phase to a specific case study, of selecting one of the variables from the main table we created during Phase 4 of the process, and its results and conclusions.

In the input phase, we chose the variable of elderly residents (65+) with a family status of single, divorced, or widowed. According to the Welfare Department of the Municipality of Haifa, these are the elderly residents who are at a higher risk of solitude. We refer to this variable as “lone elderly residents.” We applied the mutual information algorithm and assessed the dependence relationship between it and the rest of the variables in the main table, establishing that “lone elderly residents” have the highest level of dependence vis-à-vis the following variables (Figure 4):

- Correlation between the variable “lone elderly residents” and the variable “elderly residents who received food baskets during the Coronavirus [pandemic]”—76%. The source of this information was civil society elements in the neighborhood of Hadar. During the first Coronavirus lockdown in Israel, civil society elements distributed food baskets to the elderly population. That is, this work with algorithms enabled us to generate the feedback that the way in which civil society distributed the food baskets was highly correlated with the spatial distribution of the population of “lone elderly residents”.
- Correlation between the variables “lone elderly residents” and “elderly residents who receive a supplemental disability benefit”—62%. The source of this data was the National Insurance Institute of Israel. In other words, we can therefore conclude that many elderly residents who are “lone elderly residents” are also elderly residents with disabilities. This correlation’s translation into a geospatial layer showed us that this phenomenon is more prominent and widespread in certain parts of the neighborhood known for their lower socioeconomic status than in others, further highlighting the seriousness and complexity of the phenomenon.

### *Discussion and recommendations for future research*

In this study, we discussed the most up-to-date theories of the social turn of the Smart City and how our SUDT development protocol can serve as a means of generating this social turn. The study promotes the core issue of urbanism by binding together the social and physical fabrics of the city; it also contributes not only to increasing the accessibility of the urban social fabric but increases access to the social issues of the city. Its goal is to support the realm of city decision-making, with an emphasis on reducing the digital gap that characterizes the city administration’s department of welfare. In this article, we showed how the SUDT constitutes both a theoretical conception and a practical tool for responding to the challenge we sought to address in this study: to bring about a social turn in the Smart City. The concept of the Social Urban Digital Twin emerged from the adoption of two ostensibly contradictory conceptions: that of critical sociology, which views the concept of the Smart City from the side and seeks to understand it in the context of social and



**Figure 4.** Social-Spatial Visualization Top: Correlation between “lone elderly residents” (shaded blue) and “elderly residents who received food baskets during the Coronavirus” (dots) Bottom: Correlation between “lone elderly residents” and “elderly residents who receive supplemental disability benefits.”

economic power relations; and the progressive conception of technological development, which is based on a belief in the ability of technological tools to respond to the challenges of the current age.

To continue developing the field, we propose a number of further studies:

**First**, a follow-up study to discuss ways of sharing social information among public bodies and defining methodologies and protocols for doing so. The ability to continue developing the SUDT will depend largely on finding creative solutions for information sharing without infringing upon the privacy and the information security of the residents.

**Second**, research on algorithms and machine learning, which is currently in its infancy with regard to social issues. The sixth phase of our development protocol sheds new light on the subject and highlights its potential. We propose continuing to research and develop this realm through the formation of integrative working groups of data scientists, geo-information scientists, and social scientists.

**Third**, follow-up studies that assess the protocol’s applicability to other social issues beyond that of the condition of elderly residents during the Coronavirus pandemic, which was the focus of work

with the protocol thus far. These studies should report their findings and conclusions to the professional community.

In conclusion, this study adds an additional tier to the growth discourse of urban analytics and city science by marking and defining a new sub-field of research and development: the SUDT. It combines critical theory and applied practice to further social policy through the use of technological tools from the world of progressive development that also function in the world of critical thought. It also calls for and creates an opportunity for follow-up studies to continue the development and application of the SUDT in order to further the social turn in the field of Smart Cities.

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