Towards a Digital Twin of Society

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Abstract

This paper describes the potential for developing a digital twin of society - a dynamic model that can be used to observe, analyze, and predict the evolution of various societal aspects. Such a digital twin can help governmental agencies and policy makers in interpreting trends, understanding challenges, and making decisions regarding investments or policies necessary to support societal development and ensure future prosperity. The paper reviews related work regarding the digital twin paradigm and its applications. The paper presents a motivating case study - an analysis of opportunities and challenges faced by the German federal employment agency, Bundesagentur für Arbeit (BA), proposes solutions using digital twins, and describes initial proofs of concept for such solutions.

Keywords: Digital twin, digital transformation, prototype, society, stress testing

1. Introduction

The emergence of increasingly powerful digital technologies such as internet of things, virtual and augmented reality, artificial intelligence, and machine learning is ushering a new era of digital transformation in organizations. While the private sector has been at the forefront of this transformation, governmental entities are also starting to embrace the concept as a way of creating better internal processes, improved interactions with citizens, and innovative services. One particularly powerful way of combining digital transformation technologies is a digital twin - a dynamic model of a physical entity or a real-world process that can be used to observe, diagnose, control, and predict future behavior (Apte & Spanos, 2021).

In this paper, we explore the potential of digital twins to model various aspects of a society[1]. Our goal is to assist governmental agencies and policy makers in interpreting trends, understanding challenges, and making decisions regarding investments and policies for societal development and future prosperity. The paper is organized as follows. In section 2, we review related work regarding the digital twin paradigm and its applications. In section 3, we present a motivating example - an analysis of digital transformation from the perspective of the German federal employment agency Bundesagentur für Arbeit (BA). In section 4, we propose digital twin solutions for the previously identified issues and describe initial proofs of concepts. Finally, we present conclusions, limitations and suggestions for future work in Section 5.

2. Related work

2.1. Characterizing digital twins

According to a systematic literature review of 75 digital twin papers found on Google Scholar, digital twins are "(physical and/or virtual) machines or computer-based models that are simulating, emulating, mirroring, or "twinning" the life of a physical entity, which may be an object, a process, a human, or a human-related feature" (Barricelli et al., 2019). They

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are integrated systems that link the real and the virtual worlds through seamless, continuous and dynamic data exchange from multiple sources and have the ability to select and extract the most relevant features from the data, recognize patterns, learn, self-adapt and self-parameterize (Barricelli et al., 2019). Another literature review text-mining 150 Scopus, Elsevier, and ScienceDirect peer-reviewed papers identifies five clusters of digital twin characteristics and offers a composite definition: ”A set of adaptive models that emulate the behaviour of a physical system in a virtual system getting real time data to update itself along its life cycle. The digital twin replicates the physical system to predict failures and opportunities for changing, to prescribe real-time actions for optimizing and/or mitigating unexpected events observing and evaluating the operating profile system” (Semeraro et al., 2021). Digital twins are less expensive than physical replication and allow simulations in seconds. They are especially useful when physical replication is not even possible (and when, at best, only pilot projects can be observed, such as the unconditional basic income in Finland (Kanta.fi, 2020; The Guardian, 2020)).

Many digital twin applications (Barricelli et al., 2019; Jones et al., 2020; Semeraro et al., 2021) focus on manufacturing (smart manufacturing and digital factories) and aviation (predictive maintenance of equipment and simulation of weather and performance scenarios) - not surprising given these fields' long history of modelling and simulation. In healthcare, digital twins are built for medical devices (predictive maintenance and performance optimization), patients (personalized medicine), and body parts (testing different treatment options and their likely effects on patients ”in silico”) (Barricelli et al., 2019; Semeraro et al., 2021). In city management, digital twins can help model buildings, traffic, and emergencies (Semeraro et al., 2021). In the maritime and shipping context they can help optimize the design and operation of a ship's structural and functional elements (such as the hull of a ship affected by wave and weather changes) (Semeraro et al., 2021; VanDerHorn & Mahadevan, 2021). Other applications include meteorology (weather forecasting, real-time weather monitoring for air traffic management, or testing weather models) and education (personalized education) (Rasheed et al., 2020). Researchers working closely with industry partners are developing digital twins for sustainability (to lower energy consumption and decrease greenhouse gas emissions), smart innovation (to add smart sensing and modeling features to physical entities such as wind turbines, roads, dams, plants, etc.), and health and safety (for telehealth and for prediction of viral spread) (Apte & Spanos, 2021). The study of limitations and challenges of digital twins - such as threats of technocratic control, impacts on human rights and human dignity, and lack of protection mechanisms to prevent unintended consequences (Helbing & Argota Sánchez-Vaquerizo, 2022) is also ongoing.

2.2. Digital twin applications in society

Most of the research on digital twin applications in society is in the smart city area. The concept of a digital twin city (DTC) combines the physical entities of a city with a virtual representation of past, present, and possible future states (Deng et al., 2021). A DTC helps the government improve the city's efficiency (e.g., energy consumption, disaster management, transportation). Deng et al. (Deng et al., 2021) define a DTC as a platform for urban operation and maintenance, characterized by self-perception, self-decision, self-organization, self-execution, and self-adaptation. Based on a literature review, they propose the following technologies for a DTC: a) surveying and mapping technologies for real-time holographic representations (e.g., spatial structure); b) building information modelling in order to allow a virtual disassembly, modification, and operations of physical building entities; c) 5G-enabled Internet of Things (IoT) for monitoring and managing of urban services based on real-time data received from various sensors (e.g., temperature, physical movements); d) blockchain to support decentralized communication between physical and virtual entities ensuring data accuracy, authenticity, and security; and e) collaborative computing for handling the huge amount of data (e.g., produced by sensors) by guaranteeing low latency. For example, urban road planning is a complex decision problem. By combining DTCs with multi-criteria decision making, the planning process can consider various effects, such as traffic congestion, air quality, and noise pollution (Jiang et al., 2022). Furthermore, during the construction the continuous change of the urban road system is supported by real-time traffic congestion and alternative route proposals.

A successful DTC implementation can be found in the city of Zurich (Schrotter & Hürzeler, 2020). The DTC contains 3D spatial data including the whole public space (e.g., streets), utility infrastructure (e.g., electricity cables, water pipelines), and detailed models such as selected facades, bridges, and high-voltage lines. The DTC is used in different scenarios such as development planning and sectoral planning of heat reduction. This study also describes features DTC spatial data should have: spatial data must be Open

Government Data, visualized attractively and adapted to different interest groups, with automated access and simplified retrieval and processing (Schrotter & Hürzeler, 2020). Lu et al. (Lu et al., 2020) describe a DTC pilot project at the University of Cambridge and highlight lessons learned and challenges involved in developing DTCs from a technical perspective. They posti that the development of DTC can be considered successful when: a) the goal and value are clearly defined (insight and value creation); b) the process of collecting, updating, transferring and integrating data and models throughout the DTC's life cycle is well designed and practical (federation); c) the DTC can adapt, develop and expand as technology advances (curation and evolution); and e) there is a valid control strategy to guarantee DTC performance (security, openness and quality) (Lu et al., 2020).

There are also applications of the DTC concept in disaster management, receiving citizen feedback, analytics, road planning, water infrastructure impacts during Covid-19 and areas of health, e.g., (Fan et al., 2021; Ford & Wolf, 2020; Pang et al., 2021; Pesantez et al., 2022). The increase in the frequency of natural or man-made disasters has prompted the need to develop tools for situation assessment, decision making, and coordination among various stakeholders. Interdisciplinary research has emerged to combine DTC and artificial intelligence (AI). Fan et al. (Fan et al., 2021) summarized this research and propose four main features characterizing DTC applications in disaster management: a) multi-data sensing for data collection (AI-enabled remote sensing, social sensing and crowdsourcing technologies); b) data integration and analytics to draw important insights needed by disaster responders and relief actors; c) multi-actor game-theoretic decision making for improving disaster response training and network-centric coordination; and d) dynamic network analysis to improve the efficiency of disaster management efforts.

DTCs for disaster management are valuable in the context of infectious disease epidemics as well. For example, Pesantez et al. (Pesantez et al., 2022) discuss the use of DTC in combination with advanced metering infrastructure to model the impact of water quality during the COVID-19 pandemic. Pang et al. (Pang et al., 2021) propose a combination of DTC and federated learning to support decisions during pandemic crises. They develop a model containing different metrics (e.g., COVID-19 cases, testing number) and applied a collaborative training process based on real data from multiple DTCs. The results can be used to realize an intelligent model for future pandemic situations.

DTC also allow the simulation of possible selection options, thus facilitating urban planning decisions in the real world. An good example of such an application is a public and open digital twin of the Docklands area in Dublin, Ireland proposed by White et al. (White et al., 2021). They used the digital twin to engage citizens and obtain feedback from them on urban planning and policy, such as skyline and green space planning simulations. User feedback and suggestions can be collected through form-based methods with possible selections, and tagging models, allowing tag problems or suggestions with the exact location. Furthermore, the integration of humans, infrastructure, and technology in the decision making process is seen as an important factor of DTC (Mohammadi & Taylor, 2019).

Ford and Wolf (Ford & Wolf, 2020) point to two threats to the development and implementation of DTC to manage a community through a disaster. These are risks of integration and fatigue. First, focusing on particular technologies leads to miss critical community-level interdependencies across systems, which leads to wrong decisions during a disaster. Second, if DTC does not immediately bring the expected benefits, its development may be limited or even stopped. More generally, digital twins for cities (and even nations) are characterized by increasing levels of complexity as the amount of data, networking, and interconnectivity increase, making it difficult to build accurate models, especially when the desire is to capture human behavior, opinions, preferences, and interactions (Helbing & Argota Sánchez-Vaquerizo, 2022).

3. Motivating case study: Germany's federal employment agency

In Germany, Bundesagentur für Arbeit (BA) is the federal employment agency responsible for the entire German employment market. It provides a platform for job searches, professional training to develop the skills required by the changing nature of work, career exploration and transition from school to work, unemployment and child benefits, support for work-related injuries, services for people with disabilities, as well as services for foreign workers. BA needs to constantly analyze industry and technology trends, societal changes, and European Union policy developments in order to ensure the service it provides continue to meet the needs of its constituents and the goals of the German federal government.

Several major changes in society's development affect the way BA targets to provide services in the future: digitization (automation, Internet of Things, artificial intelligence, etc.), sustainability (carbon-neutral/net-zero goals) and demographic changes (aging population and decrease in the number of available workers). An in-dept analysis of these trends (Capgemini & TLGG, 2021) identifies a number of challenges for BA. Fist, digitization is bringing about major changes to the work environment - creating flexibility and increasing efficiency and effectiveness. While the digitization trend has been amplified by the COVID-19 pandemic, which made working remotely a necessity for maintaining operations during the crisis, it is now becoming a normal way of doing business. This increases lifelong needs for re-skilling and up-skilling to keep up with technological change. Digitization also requires interpersonal and behavioral ”soft” skills to complement digital skills and support innovation. Second, Germany's and European Union's long-term goals for carbon neutrality and the associated government policies to move from fossil fuels to new green alternatives are adding to the need for new skills in the workforce. As with digitization, sustainability makes old jobs disappear but creates new jobs that require new innovation and technology skills in areas such as renewable energy, efficient energy technologies, green production methods, circular economy, sustainable transportation, and sustainable resource management. And third, demographic changes increase the pressure on the labor market and the social support system, as the number of working people in Germany will decrease by 3.4 million and the number of retirees will increase by 3 million by 2030, according to national statistics. This leads to more competition among companies to find employees with the right technology skills and increases the need for people-facing workers in the health and elder care sectors. To add more workers to the economy, BA needs to enhance its ability to recruit foreign workers with a variety of specialized skills and fully integrated them into the German labor market and society.

To respond to these challenges, BA has the opportunity to digitally transform itself (Capgemini & TLGG, 2021). By using technology to support work processes, automate services, engage in evidence-based decision-making, and constantly innovate, BA can become a ”working platform of the learning society” (Capgemini & TLGG, 2021). To this end, BA can create a technology platform that enables the identification of trends, skills gaps, and training needs in the labor market and for individual workers - by harnessing data from a variety of sources and using data-driven (predictive) models such as digital twins for forecasts and decisions. The platform needs to support employee lifelong learning and placement - from initial training to ongoing development of skills throughout life - with special emphasis on individual needs and fair, non-discriminatory placement algorithms. The platform also needs to enable employees to communicate their skills (acquired either through formal training or through work and life experiences) to potential employers with digital certificates. Last, but not least, BA should continuously invest in its own human resources to build is digital infrastructure, optimize its processes and innovate. In the next section, we describe how a digital twin of society can help BA address these challenges.

4. Towards a digital twin of society

A digital twin of society is a collection of individual interconnected digital twins capturing different aspects of society and its members - such as achievement (formal education, on the job training, etc.), behavior (employment status, migration, etc.), and well being (health, happiness, etc.). The digital twin of society can be one of the elements of the digital public space - an open public digital platform ecosystem that enables exchange of data and services (Keller & Tarkowski, 2021). The digital twin requires integration of multiple data sources to reflect development and trends in all these areas. The availability of open data - which can be freely used and shared - is essential for building such a system. Initiatives supported by the European Union and its member states (de Juana-Espinosa & Luján-Mora, 2020) as well as by international organizations such as the Open Government Partnership are focusing on government transparency, collaboration, participation and accountability and are making open data a reality (Attard et al., 2015). Examples of such data sources include: a) Germany Open Government data: govdata.de; b) European Union open data portal: data.europa.eu; c) Esri Germany location-based open data offerings: storymaps.arcgis.com and opendata-esri-de; d) Germany's federal agency for cartography and geodesy (Bundesamt für Kartographie und Geodäsie, BKG): gdz.bkg.bund.de; e) Germany's federal statistical office (Statistisches Bundesamt): destatis.de; and f) Germany's Ministry of Economics, Innovation, Digitization and Energy of the State of North Rhine-Westphalia: opengeodata.nrw.de.

A digital twin of society can help government organizations such as BA easily visualize trends and improve decision and policy-making. In BA's case, the digital twin of society can help guide their future strategy by identifying areas where they need to focus in order to prepare the German society for effectively managing the upcoming changes in job types, skills, and re-training and re-skilling needs. The following subsections present several illustrating examples and proof of concept implementations.

4.1. Digital twin of education

A digital twin of education can help BA analyze labor market demand and education, geographically and over time. If gaps are identified, BA can take action such as promoting and encouraging educational initiatives for desired skills in the affected regions. A prototype implementation of such a digital twin is shown in Figure 1. The prototype is based on Python, Folium and Open Street Map. Figure 1 shows the trend of students in primary and secondary schools for Germany per state from 1999 to 2020. The visualized data is from the German Federal Ministry of Education and Research(“Schüler/-innen an allgemeinbildenden Schulen nach Klassen- bzw. Jahrgangsstufen, Bildungsbereichen und Ländern”, n.d.). The data is pre-processed and transformed into the desired form, then it is mapped onto an interactive map and timeline. Using a drop-down, the different school grades can be displayed. In addition, the timeline can be traversed. The color scheme shows the percentage of students in grade at that point in time. While the prototype implementation is quite specific to the data set, the underlying concept may be transferred to other social data such as labor market movements or the happiness factor. The way the data is processed and visualized makes it accessible and facilitates communication and decision-making.

4.2. Digital twin of social happiness

Happiness is the product of many aspects of life, including work. There are many indicators of happiness of a society - see for example, The United Nations Sustainable Development Solutions Network’s World Happiness Report (Sustainable Development Solutions Network, 2022) for more than 150 countries worldwide based on six variables: income, healthy life expectancy, social support, generosity, freedom and trust. Analyzing data on this subject will allow BA to understand how its actions - to promote lifelong learning and employment opportunities - affect employee happiness. A digital twin of social happiness based on subjective experiences of individuals could help BA answer questions such as: a) ”What makes society happier: education or income?”; b) ”Is self-employment or employment more satisfactory?”; c) ”How do depression and anxiety affect the unemployment level?”; d) ”What kind of work makes people happy?”; and e) ”How do salary and other career aspects affect an employee’s level of happiness?. This can enable BA to create simulations and forecasts of people’s work preferences and implement new programs to match emerging needs. A digital twin could also model geographic and temporal trends in the social happiness at European Union level. For example, knowing which European countries have high happiness levels can help companies determine the location of their offices or identify the best places to recruit remote foreign workers.

4.3. Digital twins of the labor market

A digital twin of the labor market continuously maps developments in labor market variables such as number and type of jobs available, number and qualifications of job seekers, or most in-demand skills. It creates the basis for evidence-based decisions for BA, companies, the workforce, players in the education landscape and for political stakeholders. By collecting and contextualizing data in a structured way, BA can link it with other data relevant to the labor market, such as demographic changes. The data provide derivations for resource management and the effectiveness of different measures taken by BA. Learning algorithms can then calculate when individuals are likely to need services. Thus the digital twin enables ”predictive matchmaking” for anticipatory offers and services. The next step could be the construction of a digital twin of a job seeker to map educational and career choices. Looking for a job requires a lot of time and effort. If BA can offer job seekers better information about the labor market and employment opportunities, this will increase their chances of finding a better job and reduce their search costs. It will also help them to create simulations and forecasts concerning their professional career. Thus BA can enable self-determination, self-education and self-identification for job seekers in return for sharing information about their career path. This can improve the efficiency of the job search process and the quality of education. Figure 2 depicts a labor market digital twin prototype which interactively shows how unemployment in Europe evolved from 2009 to 2021 (based on data provided by (Eurostat, 2022)). The code is available on GitHub (Sultanow, 2022).

4.4. Digital twin of social equity

Social equity is becoming increasingly important in today’s world. A digital twin of social equity can help BA and other public or private organizations understand inequalities and take measures to alleviate them through specialized investments and services. Below we discuss data sources and metrics for building such a digital twin. In the USA, an approach of how to measure social equity is Seattle’s Racial and Social Equity Index, a planning and investment tool that ”combines information on race, ethnicity, and related demographics with data

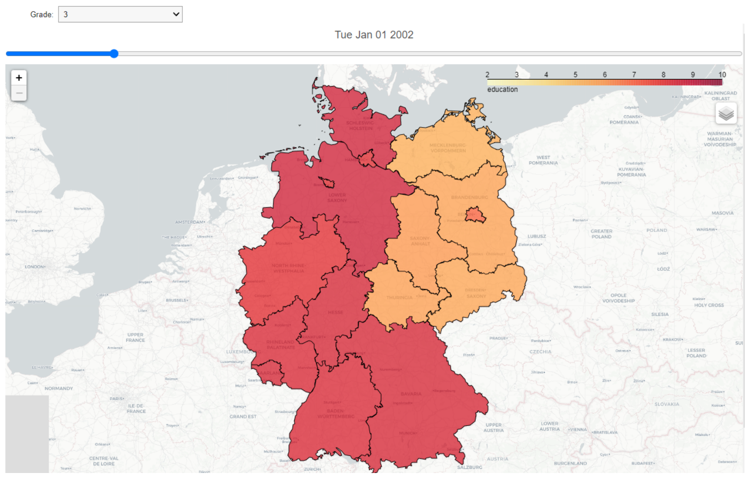

Figure 1. Interactive prototype: German students at primary & secondary schools by grade level and state

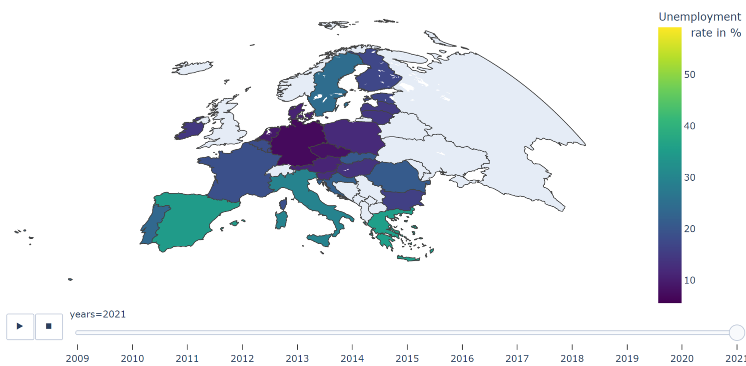

Figure 2. Interactive Prototype: Unemployment rate in Europe

on socioeconomic and health disadvantages to identify where priority populations make up relatively large proportions of neighborhood residents" (Seattle.gov, 2022). Similarly, the Social Equity Atlas (Wake County, NC, 2022) is a project in Wake County, North Carolina that uses socioeconomic and demographic data to analyze community vulnerability, economic health, food security, and overall equity issues in the county. Enste and Wies (Enste & Wies, 2014) describe how similar measures for social justice can be developed: "In many countries, the issue of justice is high on the political and social agenda. In many cases, people believe that social justice has declined in recent years. It remains unclear what is meant by justice and what is the standard of comparison. The Justice Index of the Cologne Institute for Economic Research therefore measures justice on the basis of six different dimensions (justice in terms of needs, performance, opportunities, income, rules and generations). Developments in 28 OECD countries are then made measurable and comparable on the basis of over 30 individual indicators to enable a realistic comparison" (Enste & Wies, 2014). Six dimensions of equity are identified based on an extensive literature analysis: a) needs-based equity (guaranteeing the basic needs of each member of society); b) performance equity (each individual should benefit from society's prosperity to the extent that he or she has contributed to it); c) equity of opportunity (all members of society must be given the same chances); d) income equity (the greatest possible equal distribution of wealth); e) regulatory equity (the laws of social coexistence must apply equally to everyone and be transparent and comprehensible); and f) intergenerational equity (making decisions that do not put future generations at a disadvantage compared to the present generation) (Enste & Wies, 2014).

4.5. Digital twin of health in society

Measuring the health of the population has become increasingly important during the COVID-19 pandemic, when digital trackers for infections, hospitalizations and deaths have provided a valuable lens for understanding the evolution of the disease across different geographies. There is tremendous potential for building digital twins in this area - not just for simulation of epidemics and prediction of future threats, but for monitoring other important health indicators (prevalence of different diseases and medical conditions, numbers of people needing specialized or long-term care, access to healthcare facilities, life expectancy, etc.) and investigating geographic and temporal trends and differences. At the macro level, life expectancy can be a useful indicator for overall population health and exploring correlations with other societal trends in happiness, equity, education, etc. Digital twin models in this area can help organizations like BA understand and predict population numbers, needs for social services, and demand for health and elder care jobs, as well as enable them to design and offer programs and policies to address expected changes.

4.6. Digital twin of society as a service

The prototypical visualizations shown so far are specific to one use case. In a proof-of-concept Python implementation based on Plotly Dash, we explored a more generic approach. The goal of the web application is to integrate the advantages of all shown prototypical implementations for specific cases into one application and thus create generalizability. A screenshot of the application is shown in Figure 3.

Import and pre-processing. Data can be imported into the digital twin using a file browser. Using a drop-down, a separator can be selected. Due to the different data structures, it is necessary to specify certain requirements for the visualization. The data set needs to have geographic and time information as a separated column as well as a dependent feature. Using a reshape option, the data set can be reshaped. The settings can be exported and imported again in order to make recurring visualizations. A table shows the data imported. To determine whether reshaping is needed, basic statistics about the imported data is shown (mean, max and min values as well as the ability to determine a growth rate for a specific window in time).

Visualization. Data is visualized using a multi-line chart and a choropleth map. The multi-line chart provides the ability to individually show and hide time series. The adjacent map uses the geographical information in order to highlight the location on a map. The slider below the map allows the traversing of the timeline, and the color assignment to the dependent characteristic changes accordingly.

Prediction. To enable a predictive digital twin, a simple forecast option is provided. The prototype supports Facebook Prophet and linear regression. The final plot shows the observations, the regression fit and the resulting predictions. Using the slider above the prediction plot, the prediction window can be limited.

5. Stress testing

Policy makers are increasingly challenged by complexity and uncertainty in their decisions since some of today's most pressing issues, such as mass migration, climate change or the deployment of artificial intelligence, are likely to have unintended and unexpected consequences (Tõnurist & Hanson, 2020). Sudden and disruptive events that cause great and reverberating impacts across sectors and geographies - high-impact, low-probability events (HILPs) - are typically referred to as 'black swans' or 'wild cards' (European Parliamentary Technology Assessment, 2013), (Mendonça et al., 2004). They may cause significant changes in the evolution of specific trends or social systems. They have the potential to challenge and transform existing knowledge because the risk for their occurrence was not previously known, which is why they are also referred to as 'unknown unknowns' (Tõnurist & Hanson, 2020). In the past decade, European policies were stressed by a number of such events - including the influx of migrants, the Brexit referendum result, the Covid-19 pandemic, several climatic extreme events, as well as the war in Ukraine and the related energy crisis. Stress testing can help policy makers address the increasing uncertainty they face by assessing the performance of existing or proposed policies against a range of scenarios, and adjust them accordingly. This results in more robust policies that have a greater capacity to remain functional in the face of shocks and adapt to situations developing from a disruptive event or worst case scenario (European Parliament, 2022).

Stress testing is a simulation exercise in which policy, legislation, or strategy are subjected to theoretical changes. Digital twins can help run such scenarios with parameters or input data to simulate extreme but plausible events and states. Stress testing does not mean to predict the future but to prepare and equip policy-makers to address disruptive events. Stress testing scenarios must be executed periodically to capture changes in data, trends, responses to policies, events in society, changes of macroeconomic conditions. The models must be transparent and allow the review of intermediate data and final results. The scenarios, workflows, rules and processes must also be transparent and auditable. Modelling approaches might vary and compete with each other to better

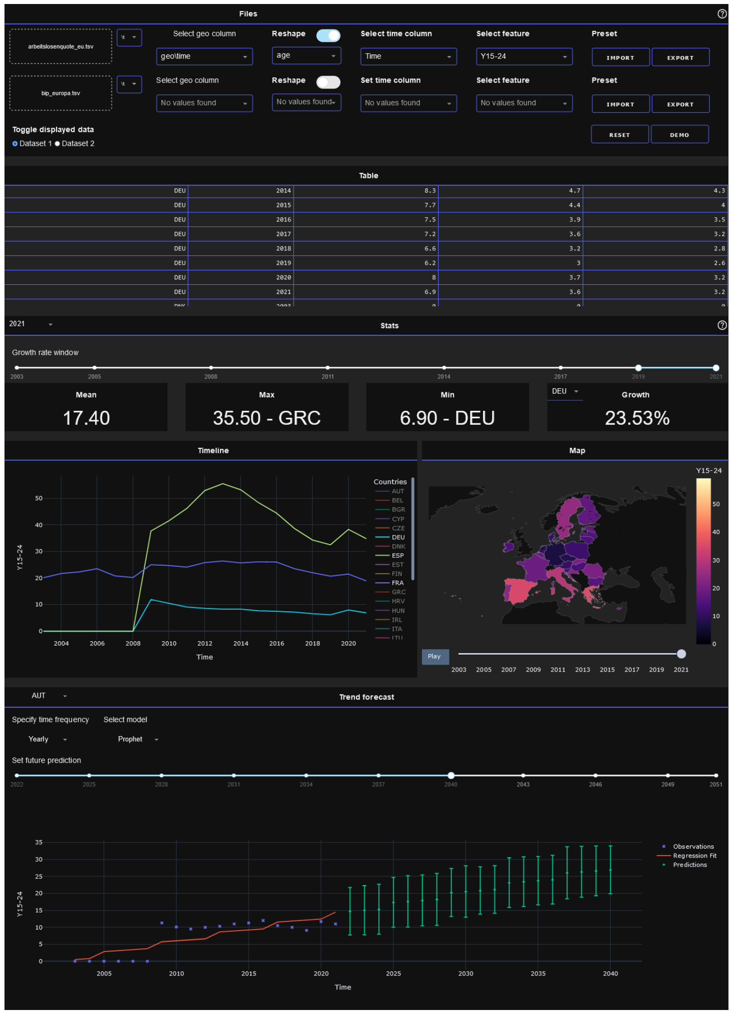

Figure 3. Interactive Prototype: Digital Twin as a Service (Unemployment Rate in Europe Using Data from (Eurostat, 2022))

describe the uncertainty. There are two important caveats (Carlsen et al., 2017): a) presenting policies in simple numerical terms risks a spurious, unhelpful, and even dangerous illusion of confidence; and b) finding ”optimal” policy solutions is unlikely under extreme scenarios. Therefore, quantitative stress-testing should focus more on describing and quantifying the possible consequences and related robust adaptations for dealing with them. We believe that a structured methodology and governed technology platform is required to perform regular quantitative stress-testing of current policies and strategies as well as interventions and planned changes. A project to develop stress testing scenarios for digital twins of society is ongoing, and preliminary details, including descriptions of the methodology and modelling approaches, can be found on GitHub (Sultanow, 2022).

6. Conclusions, limitations and future work

In this paper we discuss the development of digital twins for society. We provide a motivating case study from the German federal employment agency, and discuss how visualization, simulation and prediction of trends in several areas of society can help the agency address digitization, sustainability, and demographic challenges and prepare for the future world of work. We also describe several prototypes showing how digital twins in these areas could be implemented and how a more generic digital twin might look like. This collaborative work is ongoing, and we will incrementally improve the prototypes and use cases.

One limitation is the need to build data set-specific solutions, which complicates development of even fairly simple digital twins. With the digital twin as a service prototype, we provided a more generic solution. However this only supports time series data and external pre-processing may be required. The implementation shows the potential in striving for a generalizable solution. Guided dialogs may be further implemented to initially pre-process the data into a required form.

Working on the prototypes has shown that building a truly generic solution for any case is difficult because the data required for a complex digital twin is extremely diverse and comes in different formats from different sources, with no common standards. The data is inherently complex, is aggregated in different ways depending on the source, and is sometimes incomplete. The metadata usually requires manual processing. Our experience building the prototypes suggests that the open data tables are designed primarily for human comprehension rather than for automatic processing. Other researchers noted similar challenges, including ”lack of a single point of access to the [open government data] portals”, which ”makes it difficult to locate and access the open data they provide” (de Juana-Espinosa & Luján-Mora, 2020), ”a large number of diverse data structures that make the comparison and aggregate analysis of government data practically impossible” (Attard et al., 2015), and a need for manual search and extraction (de Juana-Espinosa & Luján-Mora, 2020).

Future research can investigate how to represent relationships between various socioeconomic variables with geographical reference to analyze trends, investigate patterns across and within regions/countries, and discover hypotheses to be tested. Additional variables for future prototypes include innovation, population growth, democracy index, emigration and immigration rates, press freedom index, political engagement, militarism, perceptions of security, and demographic composition of society. Countries such as the USA provide a great amount of society-related data which can be used for structure and anomaly detection and for transfer of findings for future testing in other countries. Stress testing scenarios, prediction of future trends, as well as simulation of scenarios with hypothetical data/parameters can be areas for future design science research. Last, but not least, future studies can investigate the value, trustworthiness, and ultimate adoption of digital twins by organizations around the world.

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