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TUTORIAL

Digital Transformation in the Public Administrations: A Guided Tour for Computer Scientists

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ABSTRACT The goal of Digital Transformation of the Public Sector is the achievement of a better quality of life for citizens, via a more responsive and transparent administration and governance. By now it is clear that technological innovation, both in terms of computer architectures and software systems, is a crucial component of it, yet not sufficient. Indeed, a cultural, organizational and legal shift in how public organizations operate and relate to the citizens is also required. Nevertheless, computer scientists can play a key role in such a transformation and, given its impact on Society, it is essential to achieve a broader level of awareness of it and involvement in it of those scientific and professional figures. To this end, a technical map specifically designed for computer scientists, but properly placed in the context of the cultural, organizational and legal changes mentioned above, would be highly beneficial. To date, such a map is missing, to the best of our knowledge. The main contribution of this Tutorial is to provide it, together with a guided tour describing which key technological aspects enable and drive such a transformation. More specifically, based on a careful analysis of the available scholarly literature, that does not seem to include any Computer Science textbook material, a model of such a transformation is proposed, together with carefully selected examples incarnating it to show its validity: the cities of Barcelona and Chicago. Finally, a look at the future of this area is also provided.

INDEX TERMS Agile software development, computer systems organization, cloud computing, computing methodologies, machine learning, data knowledge and engineering, design and engineering of services for e-citizens, digital government, digital transformation.

I. INTRODUCTION

We all are citizens of a digital era, which offers new possibilities, new rights, new duties [1]. Digital citizens use ICT technologies to communicate, access information, and participate in social, economic, and political activities. The impact that the advent of this new era has had is not limited to citizens, but also involves public administrations (PAs, for short), being directed to be more and more digital in how they work, relate, and interact with citizens. As a matter of fact, a Digital Transformation (DT, for short) in the PAs is taking place. To date, there is no formally accepted definition of such a transformation: as pointed out in [2], there can actually be many of them. In the context of this work,

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we use the definition below that attempts to summarise most of them.

DT is the process of integrating digital technologies and solutions into all aspects of the activities of an organization, whether public or private. In turn, such an integration, in particular in the Public Sector, implies deep changes in organization and management, in order to account for regulations as well as for a citizen-centric methodology. For those reasons, it can be a complex, never-ending, and often discouraging process.

The pursuit of DT represents a cultural, organizational, social, legal and technological shift that leads organizations to initiate a change in the way they operate and relate to their users, trying to be more and more responsive to their needs. It must have an associated strategy, focusing on creating the capabilities within the organization to take full advantage of the opportunities of new technologies and their impact in the most useful and most innovative manner, keeping in mind that the private and public sector differ. Indeed, the technologies used in the private sector cannot be applied immediately in the public one without an analysis of possible differences of impact [3]. This is due to the fact that DT in the private sector concerns how it impacts employees and how digital technologies and processes improve the productivity and quality of the products offered to customers. In the public sector, DT has a different scope because it impacts not only the citizens, who are scarcely comparable to customers, but also the governing and administrative processes, and the nature itself of the social contract [4].

From now on, unless otherwise specified, in our paper DT refers specifically to the Public Sector.

Given the above, that sketches how complex DT may be, the remainder of this section is dedicated to highlight: (a) the motivation for this Tutorial; (b) the contribution it gives to achieve a better understanding of DT in the PAs to computer scientists and (c) the organization of its remaining part.

A. COMPUTER SCIENCE: AN ENABLER AND DRIVER OF DIGITAL TRANSFORMATION IN THE PUBLIC SECTOR

As DT projects are implemented, citizens become eager for accessing digital services supporting their activities and life. This requires public institutions to ensure that their digital solutions are user-friendly, secure, and accessible to all citizens [5]. Several institutions and administrations in the Public Sector are exploring the opportunities offered by Digital Transformation technologies to enhance their organizational flexibility necessary to adapt to changing contexts and meet new government and citizens demands [6], [7]. More in general, DT has become an increasingly pressing issue in recent years, with the growing need to modernize government services and improve their efficiency and transparency with respect to the needs of citizens.

It is not surprising that there are several areas in this context where Computer Science can have a major impact, while receiving further stimuli for its growth. One of them is the development and implementation of digital infrastructures to support specifically the Public Sector, with a range of topics that goes from privacy and security aspects of the data and of their processing to smart cities [8]. This includes creating systems for data collection, storage, and analysis [9], as well as building networks and platforms for communication and collaboration among different public institutions [10]. Another one is the study regarding how to make government data more accessible, transparent, and useful for the citizens, their administrations, and other stakeholders. This includes developing standards for data sharing and interoperability, as well as creating tools and applications that enable citizens to engage with public Open Data in useful ways [11].

Although the two example areas mentioned above, where computer scientists can contribute to DT, are already very significant, due to the revolutionary role played by DT in Society, it is to be expected a level of awareness of such a process and involvement in it of those scientific and professional figures far broader than the one we have now: although technology is not enough for a DT, there is no DT without technology.

The achievement of such a goal would certainly be facilitated, if there were a methodologically coherent overview of the key technical aspects of DT, tailored for computer scientists, but placed in the proper context of the cultural, organizational, social, and legal issues that characterize such a complex process, with a careful balance to avoid that those latter ''overpower'' the technical aspects proper of Computer Science. The aim of this Tutorial is to provide such an overview, accounting also for a proper balance with the context characterizing DT.

B. OUR CONTRIBUTIONS

Once that the motivation for this Tutorial has been clarified, the next step is to describe the research questions we started from. The definition of DT lends itself to many variants. Hence, the formalization of the related research questions may have many variants. The one adopted here is: ''What are the technological and computational issues characterizing the Digital Transformation in the Public Sector, including their interaction. '' Given the fact that responsiveness to change in needs and demands of the citizens is one of the essential aspects, and given that at the technical level, such a responsiveness is best accounted for by Agile methodologies, we focus our literature search on three keywords: Agile, Digital Transformation, Public Services.

Based on a careful analysis of the available scholarly literature, we identify key areas of DT with competencies specific to computer scientists, we present the interactions among those areas and finally account for the need for responsiveness in DT. We also provide examples. The end result is a model, in the form of a graph, that accounts for DT. Finally, we also provide future directions.

TABLE 1. A synopsis of the literature selection process. The terminology is as in the main text. The first column indicates the stage of the selection process. For each stage, the number of selected papers is indicated. Only rows 3-5 contribute to the total.

PHASE	OUTCOME
Search	5,881
Inclusion, Exclusion, Duplicate Elimination	151
Eligibility based on Full-Text	151
Forward Snowballing	24
Background	62
TOTAL	237

C. ORGANIZATION

The main body of this Tutorial has a two-layer structure. The first layer provides an overview of the main technical aspects of our model. The second layer is for the reader who is willing to get additional details. In particular, the organization is as follows.

Section II describes how we selected the literature at the basis of this Tutorial (after checking that no similar Tutorial has been published); Section III introduces our model and it is the first layer of the main body. It is for a reader that wants to get acquainted with DT. Sections IV-VII provide an additional level of the detail, adding a second layer to the main body. It is for the reader that is interested in getting a deeper, although initial, understanding of DT.

II. LITERATURE SELECTION

Our effort to provide a systematic homogeneous presentation of DT is based on the current State of the Art. Therefore, it is advisable to resort to established methods to collect relevant papers for a Systematic Literature Review (SLR). However, there are differences. Indeed, while an SLR usually describes relevant papers covering the State of the Art in order to answer to some research questions, this Tutorial uses the selected papers to extract the main ingredients of DT and to propose models for it, with the addition of illustrative examples. Once stated such a fundamental difference, the paper selection process proceeds in stages, each of which has an outcome in terms of papers that are analysed and selected for inclusion in this study. A synopsis of such a process, with the corresponding outcome, is provided in Table 1, and details now follow.

The first stage consists of a literature search in the ACM and IEEE digital libraries, in addition to Google Scholar. Given that, as stated in the Introduction, the focus is on Agile methodologies, the query term is very focused: ''agile'' AND ''digital transformation'' AND ''public services''. The period of time is January 2017-February 2022.

The outcome is 1,993 references from Google Scholar, 745 from IEEE, and 3,143 from ACM Digital Library. For ACM, only the first 2000 items (sorted by relevance) could be accessed, since the search engine limits itself to report that the bottom 1,143 ones are very similar to those available for display. Therefore, over the three databases we have consulted, we have collected a total of 5,881 papers.

The second stage consists of an inclusion/exclusion process, with duplicate elimination. The selection criteria are as follows

- The papers should be centered on DT in the Public Sector, with focus on software development topics and related technical aspects.
- The papers must be written in English.
- The papers must be published and available in scientific journals and conferences.

The result of this stage is 151 papers.

The third stage consists of assessing the eligibility of the 151 papers for consideration, based on a full text evaluation. They all passed such a quality check.

Following standard practices is Literature review, we have considered paper that cite the ones that are output of the third stage. This is denoted as forward snowballing. Based on relevance and full text reading, a total of 24 more papers were selected. This is the fourth stage.

Finally, since the guide to authors of this journal encourages the inclusion of background material for tutorials, in order to make them accessible to a wide audience, we have included a total of 62 papers. They provide background regarding technical issues, e.g. Open Data [12], but given that the Tutorial deals with Governments, Municipalities and Public Organizations, we felt as appropriate to include also key papers, not accounted for in the scholarly literature that deal with fundamental standards and regulatory issues in DT, e.g., [13].

III. THE MAIN INGREDIENTS OF THE DIGITAL TRANSFORMATION IN THE PUBLIC SECTOR

Based on the definition of Digital Transformation outlined in the Introduction, we now present its primary aspects across four domains identified through a comprehensive analysis of the papers we have considered for this research. We also discuss the interactions among these domains. The end result is a graph model of DT, proposed here for the first time, and that can be used as a ''summary map'' to describe the DT process. Moreover, the concepts and notions summarized by the model are exemplified via two paradigmatic examples: the Cities of Barcelona and Chicago. Such a choice is motivated by the fact that, although complex cities, their DT scale is well suited for the crisp identification and evaluation of the specific actions regarding their transition to digital.

A. A GRAPH MODEL FOR DT

With reference to Table 1, rows 3-4, there are 175 ''core papers'' that characterize this Tutorial, the other being background papers included to make its content accessible to a wide audience. We concentrate now on an examination of the former 175 paper, in order to obtain a synopsis of the computer science areas they belong to. Although, as expected, they address various aspects related to how

PAs plan and implement their DT strategies, 167 out of 175 predominantly focus on one of four knowledge domains: **Data** (28 papers), **Technology** (55 papers), **People** (31 papers), and **Process** (53 papers). For completeness, the remaining 8 do not have a specific and well determined focus, being mostly comparative studies involving various DT initiatives around the world, e.g., [14]. The mentioned domains are briefly discussed below, providing first the key points characterizing them.

- **Data**.
  - **Key Takeaways.** Open data are the main source of information in the DT process of a PA, being crucial for administrators and citizens. Their collection and management should include an interoperability framework to handle their heterogeneity in order to derive actionable insights from data to enhance public service delivery and policymaking.
  - **A First Level of Detail.** The availability of public data has changed significantly over the past decade, resulting in a greater awareness of how it is collected, represented, owned, and managed. As a consequence, the data life-cycle has changed with respect to the past [15], [16], [17], [18], [19], posing new technical problems even to mature areas such as databases [20] and requiring new ways to design software for their management [21]. As far as this Tutorial is concerned, it is important to point out that data are no longer seen as an asset to exploit for a competitive advantage, but as a social ''infrastructure'' that must be made available to policy makers and citizens to ensure and improve the well-being of Society [22], [23]. With this in mind, more and more PAs are making available their data to improve transparency and accountability [17], [24], [25], [26], [27], [28]. However, due to the heterogeneity and lack of interoperability of the data sources, major problems arise. One is how to exploit at its best the information contained in those data. Another is the realization of the sound technical principle of ''only once'', i.e., data collected by one administration should be available to other administrations. Scale factors make these problems even more difficult, since ''data'' can refer to a continent [29], a nation, a city, or be sector specific [30], [31]. In order to address the problems alluded to earlier and of which we have provided two examples, an entire data ecosystem is shaping up, ranging from infrastructures to data analysis tools and applications. Following [9], the term ecosystem is used here, instead of environment, because like real ecosystems, data ecosystems are designed in such a way to have an ''evolutionary'' part aimed at improving data quality levels over time. It is a node of the proposed graph model and, in what follows, we use the terms data ecosystem and data interchangeably. Moreover, being data the source of information that powers the DT, its corresponding node is the central one in the model, as shown in Figure 1. Additional details regarding the components of such a node are presented in Section IV.
- **Technology**.
  - **Key Takeaways**. Smart Cities seem to be a very promising technology in this context. Data Governance for the DT also needs technological support, in particular to guarantee a level of security and privacy of data that meets regulations and that it is trusted by the citizens.
  - **A First Level of Detail.** The term technology refers to hardware and software systems supporting PAs in some DT process [24], [32], [33], [34]. Digital platforms that support all stages of governance activities are in place or planned [10], since their realization is perceived as a way to increase the pace of the DT [35]. In particular, several PAs are moving to the Cloud [16], [36], [37], [38]. Smart cities [19] are becoming a recurring pillar in the DT. Blockchain technologies are also being considered, but they appear somewhat marginal at this stage [39]. Artificial intelligence is expected to play a major role, e.g, [40], [41], [42], [43], [44], and [45], although its impact and pervasiveness on privacy, transparency and accountability in the realm of DT is still under study [10]. Such technologies are useful for supporting data-driven decision-making in public administrations which, in turn, have the goal to provide a higher and higher quality of life for their citizens. In order to achieve this goal, in particular for limited geographic areas such as cities, ruling bodies and decision makers are accepting difficult and stimulating challenges related to the creation of complex digital models of cities, that would allow them to respond to the needs of citizens faster than in the past (e.g. [19]). Those new models must ensure privacy and security, making necessary for the PAs to possess regulations about data governance, e.g., the European Data Protection Act (GDPR) [13], [46], cyber-security technologies, e.g., the National Cyber-Security Agencies [47], [48], [49] and a flexible and modular strategy to data access and sharing, e.g., the European DECODE project [50]. Technology for the DT is the node shown in Figure 1. Details regarding the components of such a node are presented in Section V.
- **People**.
  - **Key Takeways.** Citizens are central for the DT. They are involved in the Co-Creation process of services and, since they are the end users of those services, they need adequate digital skills.
  - **A First Level of Detail.** The services provided by the PAs must be considered valuable by the citizens, who sustain them by paying taxes. Such a fact

has an important consequence regarding efficiency, which has had a privileged position in the design and deployment of services: the aim for it, although valuable, is by no means sufficient in generating services perceived of value to the citizens [33]. In fact, for the design of services, a people-driven delivery model is more and more the one of choice [24], [32]. Such a new model places citizen participation at the center of most service design and implementation initiatives, whose success must be evaluated by their users, namely the citizens and various kinds of decision-makers, according to their perception of the value created [51], [52], [53], [54], [55]. Interestingly, although the meaning of services valuable to the citizens is clear, the meaning of the apparently related term of "business value" in the digital PA is not so clear, although intuitively it relates to the provision of better service to the citizen, efficient operation of the services and the enforcement of the law [56]. It is to be pointed out that digital skills are essential tools unlocking the door to innovation, empowering individuals to effectively navigate today's interconnected and technology-driven world. These skills allow people to actively engage in the digital society, adjust to changes, and fully capitalize on the possibilities presented by technology [55], [57], [58], [59], [60], [61]. People for the DT is the node shown in Figure 1. Details regarding the components of such a node are presented in Section VI.

- **Process**.
  - **Key Takeaways.** Since the DT must improve the responsiveness of an organization, Agile Methodologies seem to be the most adequate for software project management. Moreover, the digital maturity of a public organization also needs to be assessed, via Index and Maturity Models.
  - **A First Level of Detail.** As part of a DT strategy whose aim, as already stated, is to obtain services that are more citizen-centered, it is to be expected that new ways of process engineering are developed and deployed [62]. Although the transition from established process engineering to new ones is not so simple [59], [63], Agile project management approaches seem to be the "best" candidates to support the mentioned transition [24], [37], [54], [62], [64], [65], [66], [67]. Another crucial aspect regarding process management is the need for new ways to measure success, i.e., in terms of a meaning of "value" that is certainly application specific, but with a rather broad spectrum. Rather than being specific on those measurements, the trend is to measure the degree of maturity achieved by the processes in the DT strategy implementation. In this regard, in the Literature available in this Tutorial, we find several papers proposing different Frameworks and Maturity Indexes, e.g., [68], with which stakeholders could measure the progress achieved in the digital transition of their Organizations. However, among the many available, the GovTech Maturity Index (GTMI, for short) proposed by the World Bank [69] seems to be the most reliable one. Process for the DT is the node shown in Figure 1. Details regarding the components of such a node are presented in Section VII.

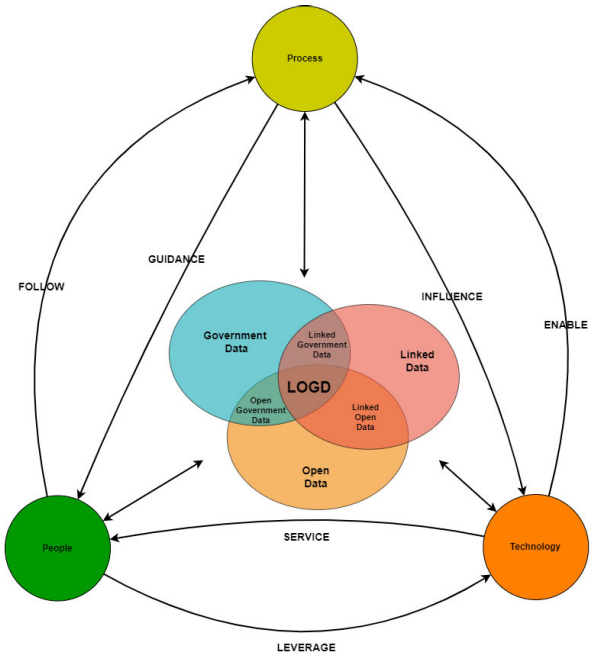

FIGURE 1. The DT graph model. Nodes represent the knowledge domains. Each edges represents interaction and dependencies between its end nodes, while the label on each edge indicates the type of relationship between its nodes, following the main text.

B. INTERACTIONS AMONG KNOWLEDGE DOMAINS

The papers we reviewed show that the four knowledge domains presented above have several mutual interactions and dependencies, summarized in terms of edges in the graph model in Fig. 1. Each edge between two nodes (knowledge domains) encodes an interaction between its end-points, while the direction of the edge encodes the dependence, i.e., an edge (a, b) indicates that a depends on b with the label indicating the nature of such a dependency. Details are provided next.

- **Interactions with Data**. At the heart of our graph model there is the data ecosystem, subject to incoming and outgoing data flows. In one direction, data is the source of information for other nodes, and in the other direction, it grows from the information it receives from other nodes. In the graph model, we encode this bi-directionality in terms of a provide/receive paradigm. People provide data and receive information

and know-how. Processes provide business intelligence, statistics, etc, and receive data. Technologies provide tools for a better governance over the data, and receive data. It should be emphasized that this paradigm encodes well the flow of information in a data ecosystem [15].

- **Interactions with Technology**. Technologies are at the service of the citizens. Indeed, given that a needs-based holism means the reunification of government services around citizens rather than business processes [70], these technologies enable it, with the end results that increase the capacity of PAs to respond to the emerging needs of citizens [57], [71]. Technologies also enable processes and facilitate their re-engineering phase [72].
- **Interactions with People**. People, who follow the processes and initiatives provided by PAs, leverage different emergent technologies [72] to enable the improvement of public processes (process re-engineering).
- **Interactions with Process**. Processes guide people, through the provision of quality digital services, to respond more effectively and promptly to the evolving needs of citizens [73]. At the same time, technological choices are often influenced by the processes, and how these are designed or re-engineered [72].

C. ACCOUNTING FOR RESPONSIVENESS

As stated in the Introduction, one of the main goals of DT is to increase the responsiveness of an organization to the changing needs of citizens. It is evident that in response to changes, such a goal can be reached by being able to: (a) quickly use novel technologies; (b) implement an inclusive strategy that promptly makes available new skills to citizens, administrators and policy-makers; (c) adopt flexible organizational models for the design, implementation and deployment of services. Those main aspects of responsiveness in DT can be summarized as follows: technological responsiveness, which naturally connects to the knowledge domain of **Technology**; inclusive responsiveness, which naturally connects to the knowledge domain of **People**; and organizational responsiveness, which naturally connects to the knowledge domain of **Process**. Therefore, it is felt appropriate to extend the graph model proposed here accordingly, as in Figure 2. We now discuss the terms we have just introduced.

- **Technological Responsiveness**. It concerns the flexibility and versatility of the solutions adopted for the collection, representation, and management of the data, together with the appropriate infrastructures to host and manage them [57], [74], [75], [76], [77]. Those solutions must account for good levels of quality and privacy. The meaning of Quality is given via a set of properties to which data should respond. Specifically: accuracy, completeness, consistency, timeliness, validity, and uniqueness [78]. As for privacy, in addition to the meaning given to it in the domain of IT security, the solutions granting it must be compliant with current legislation, e.g., the European General Data Protection Regulation (GDPR) [13]. A particularly important and novel aspect of data processing is to account for the requirement that users must be given the option to decide who can process their data and for which purposes. As for computer architectures, to date, there are many of them supporting technological responsiveness in the DT [79] and even new ones have been proposed, although it is not clear how widespread their adoption is [80]. Moreover, the possibility of migrating from monolithic systems offering services to microservices technologies is also considered [81]: although this suggestion is somewhat isolated, the results are encouraging. From our Literature Review, and in regard to the achievement of responsiveness in the DT, it is evident that Smart Cities are technologically very promising and popular, while Data Governance issues are more delicate and difficult for public administrations. Therefore, among the many facets characterizing technological responsiveness, we concentrate on those two, which are briefly discussed next.

  - **Smart Cities**. According to the ISO/IEC [82], (but see also [83]) a Smart City is "an innovative city that uses ICT and other means to improve quality of life, the 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 and environmental aspects". Moreover, based on a Literature Review, including both academic papers and practical tools, a proposal regarding the key components that make a City smart has been made in [84] and validated in [85], specifically for Brazil. The components structure that comes out is hierarchical, with the top level consisting of (a) government; (b) Society; (c) physical environment and (d) technology and data. A second level follows, e.g., point (d) is further detailed into (d.1) ICTs and other technologies, (d.2) data and information. A third level concludes the hierarchy, e.g., point (d.2) is further broken into (d.2.1) data management, (d.2.2) information processing, (d.2.3) information sharing and integration.
    Technology is essential for the sustainable development of a smart city (see above and [86]), in particular Internet-of-Things (IoT) approaches - see for instance [87], [88], [89], [90]. However, technology alone is not enough [91]. Indeed, starting from the fact that a difficulty for the realization of a smart city is the fragmented understanding of the interaction between Information Technologies and novel city governance models [92], [93], [94], changes involving public administration and management seem to be required. For instance, project and risk management need to be changed: the realization of the infrastructural innovations required to transform a city into a

smart one need to be planned carefully in order to avoid delays and over-spending [95]. Moreover, there is a need to rethink how software-intensive services are used, in order to implement more flexible infrastructures [19], [26], [96].

Section V-A is devoted to this topic, with a focus on Digital Twins [97], which is a new and promising approach to design and implement a smart city, based on the a virtual representation of its main physical city objects, including the inhabitants, that interacts with the real objects and evolves with them [97]. For completeness, we point out that Digital Twins are not a new concept, having been introduced by Greives in 2002 and have been the object of rigorous studies in order to identify their range of application domains [98], [99].

- **Data Governance**. For data governance, it is meant a set of processes, roles, policies, standards, and metrics useful for controlling data management [17], [26], [27], [96], [100], [101]. Via the effective and efficient management of the amount of structured and unstructured information coming from a multitude of PA processes and procedures, its goal is to transform those data into a strategic asset, serving the citizens while preserving their privacy. The issue of data governance is so important and strategic that a new professional figure is emerging: Chief Data Officer, with its role and responsibilities still being the object of study [102], [103]. Certainly, such a figure should be able to manage issues regarding privacy, security, regulatory compliance, access control, and the resolution of problems caused by poor data quality across the data life-cycle [15], [46], [68], [104]. Section V-B is devoted to Data Governance.

- **Inclusive Responsiveness**. It concerns how fast and broad are the cultural changes associated to the acquisition of multidisciplinary skills, ranging from digital to managerial, aimed at gaining greater awareness of the efforts of DT [57], [77]. Although inclusive responsiveness can be further divided into many categories, here we concentrate on some important ones, i.e., skills development, co-creation, and leadership. We point out that skills development and co-creation are treated synergistically here, inspired by a case study regarding the city of Chicago [52], which justifies this approach.
  - **Skills and Co-Creation**. Skills development is a well known concept that needs no further elaboration. Co-creation is a concept that strongly depends on team-building and on the digitization culture that, together with correct communication, enables the actors involved to work together to produce public services successfully [27], [55], [57], [105]. It is a continuous improvement process, in which PAs must implement the necessary tools to successfully exploit feedback from the citizens in the evolution phase of a service [51], [72], [96]. This approach changes the way in which public services are evaluated, placing the users at the ''center''. Indeed, following earlier research regarding how to measure service quality offered by the PAs [106], models and procedures for such a novel ''user-centered'' evaluation of public services are being investigated [107], [108], together with models that identify possible areas, ranging from architectures to risk management, whose improvement would result in the deployment of better services [109]. Section VI-A is devoted to this topic.
  - **Leadership**. It is perceived as a fundamental pillar driving DT in organizations, including the PAs (see [110] and references therein), in particular regarding the definition and implementation of mechanisms that strengthen the governance of digital and smart societies. Although, as pointed out in [111], strategy rather than technology is the key to success in DT, according to the study in [112], PAs that have reached a certain degree of maturity in the DT process are quite likely to have had the support of their managers and their involvement in the formulation of DT strategy plans to create new public value. Therefore, IT managers and leaders still play a fundamental part regarding innovation, even with respect to DT, but they must also have a deep understanding of which organizational culture is most effective, depending on the type of innovation being implemented [113]. In addition, they must have knowledge and training in regard to a specialized set of skills on modern technologies and related cultural changes [58], [59]. Indeed, the current level of expertise, related to emerging technologies, is a barrier to the adoption of these technologies [112], while for the creation of services perceived of value critically depends on the level of competencies that managers and decision-makers have regarding technology [114]. Furthermore, managers should behave more like product owners of the new services aiming at meeting the needs of citizens [63], [72], [96], [115], [116], [117], [118]. Yet another key to speed up DT is a coordinated policy involving National State, Local States and Municipalities [119].

    Interestingly, a technological framework based on Digital Twins has been proposed to help IT governance [120]. The framework, denoted Digital Twin for Governed IT Management (DG4GITM, for short), links the management of three interconnected systems: IT governance processes, IT management processes, and IT organizational assets by leveraging the technology of Knowledge Graphs and the resulting computational infrastructure. In particular, a given city virtual entity is created through an

enterprise ontology "GITM Domain Ontology" that is connected to the organization via data flows to populate it with real data from the resources of the organization.
This point is not the object of further discussion, since we have accounted for all the papers that cover this subject and that we have included in the Literature review.

- **Organizational Responsiveness**. It concerns the ability to adopt rapid organizational changes and to undertake new ways of operating within the PA [58], [118], [121], [122]. DT is a continuously evolving process that needs to be monitored in order to evaluate its progress and to identify directions for improvement [122]. Two key features to consider are Change Management and Frameworks, and Maturity Models:
  - **Change Management**. It refers to the ability to accept innovation while producing quality services [58], [77]. In the PA context, one of the essential parts of this point is the promulgation of laws, regulations, and guidelines, which promote the use of the services offered, enabling the creation of new public value [54], [123]. There is also a corresponding technical part regarding project management. In what follows, the change management in terms of laws and regulations is best accounted for in the areas that are affected by those regulations and laws, e.g., Data. Consequently, the part of this manuscript specifically devoted to Change Management refers to the project management engineering.
    Section VII-A is devoted to this topic.
  - **Frameworks and Maturity Models**. These models focus on the major technological, inclusive, and organizational elements of which a PA is composed, in order to be able to measure their performance and establish the progress achieved in the DT strategy undertaken [69], [124].
    Section VII-B is devoted to this topic.

D. TWO PARADIGMATIC EXAMPLES

Each Public Organization may have its own DT agenda and plan, which may vary according to factors such as geographic location, size, cultural, economic and infrastructural contexts, e.g., [14], [125], [126], and [127]. Comparative studies also exist, as for instance: China, Canada and Estonia; [128]; US and UK [129]; Australia, Denmark and the Republic of Korea [130]. Estonia is particularly appreciated in terms of DT [69], [131], to the point of being covered in the general press, e.g., the New Yorker [132], although some criticism is present [133].

Given the above State of the Art, as anticipated and motivated at the beginning of this section, we now introduce two real examples by focusing on their responsiveness aspects: Barcelona [17], [96], [134] and Chicago [52].

- **Technological Responsiveness**
  - **Smart Cities**. Barcelona, thanks to a budget allocation of 1.288 million EUR, has launched three key DT initiatives. The first one is the reorganization of data localization, through the establishment of a Municipal Data Office, headed by a Chief Data Officer. The second one is the mapping of the entire Barcelona Data System, integrating each of the existing datasets into a single data lake [70], developed for this purpose, according to the Open Standards defined by the World Wide Web Consortium (W3C) [135] and referred to as the City Operating System (CityOS). It is based on API and the data within it are now organized and interconnected thanks to the design of a standardized ontology for the city of Barcelona. An additional data-sharing platform, referred to as Data Exchange, is connected with the CityOS data lake to ensure a continuous two-way flow of data between the City and the World. The third one is the renewal of the Open Data portal through the CKAN tool [136], to ensure that public, private and personal data can be transformed into a new data-driven social infrastructure. It is worth pointing out that the city-wide data governance model of Barcelona is an extension of the open government agenda promoted by several cities around the world [137], [138], whereby cities support Open Data platforms for civic engagement and improved digital services to address a range of broader challenges, such as the implementation of Smart Cities.
    In order to make clear what follows, it is useful to recall the EU DECODE (Decentralised Citizen Owned Data Ecosystem) project [50]. Its goal is to develop a combination of decentralized software technologies, such as Blockchains and Cryptography, to give citizens more control over access and usage of their data. The DECODE technology allows data to be encoded and shared anonymously. In addition to what mentioned so far, Barcelona has leveraged DECODE through the citizen Science Data Governance pilot project, which uses environmental sensors, placed inside and outside participants homes, to detect noise and pollution levels.
    A non-trivial part of this project is the level of detail with which these data are visualized. Data from the IoT networks of sensors are collected through the open source platform Sentilo [139] in such a detailed and specific manner that individual homes can be identified. This raised concerns about the privacy of this data, as homeowners feared that its use could result in the profiling of pollution-prone buildings and homes, which would hurt house prices or insurance premiums. With the mentioned DECODE pilot project, the focus was on developing rules that would allow users to code and share their data with

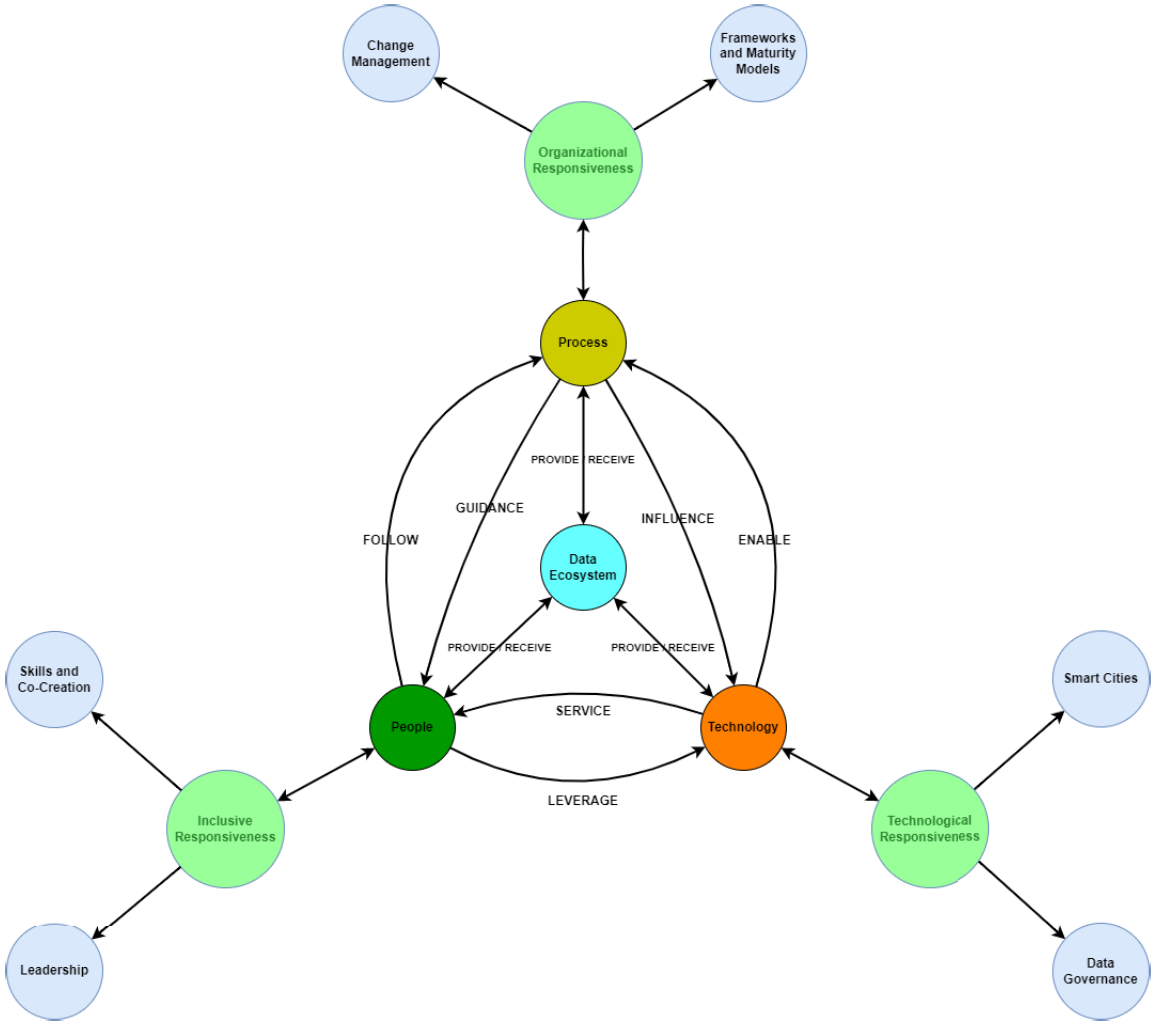

FIGURE 2. DT graph model augmented with responsiveness terms. The DT graph model in Figure 1 is augmented in correspondence of the Knowledge Domains. Namely, **Technology**, **People** and **Process**. **Technology** is augmented with the technological responsiveness aspects, such as smart cities and data governance. **People** is augmented with inclusive responsiveness aspects, such as skills, Co-Creation, and leadership. **Process** is augmented with the organizational responsiveness aspects, such as change management and frameworks and maturity models.

different target groups and with different specificities, generating more trust in the use of the collected data. Chicago, through the creation of a good quality Open Government Data (OGD, for short) portal, continuously improved since 2012, provides data visualization tools on over 550 datasets, a number that continues to grow, and is relevant to the city. Currently, in the available Literature on OGD, it is generally pointed out that the OGD in the portals that host them are often not accessible, clean, or easy to use [140]. Remarkably, none of these shortcomings seems to have been reported for the City of Chicago. Indeed, from the responses acquired through interviews, several interviewees were appreciative of the availability and quality of the OGD that are available on the Chicago OGD portal [141]. This goal was achieved through a careful processing pipeline in which data were extracted from data owners, e.g. PAs, cleaned and transformed through data cleaning techniques, and uploaded periodically to the OGD portal. Approximately 99% of the data in the OGD portal follows this processing pipeline. Maintaining the data quality levels present on the OGD portal requires great citizen participation, and an active engagement of the PAs that are owners and providers of this data [11]. With this initiative, Chicago is becoming a reference model of increasing sensitivity to data, which is useful for the creation of digital services, following a paradigm that is more and more open and collaborative, and less and less driven by top-down approaches [11]. Another important example of Smart Cities in Chicago is in the reduction of the exposure of citizens to foodborne diseases [142]. The City of Chicago, in collaboration with its Department of Quantitative Research and Analysis of Allstate, has developed a predictive machine learning model

that takes into account various data sources, such as waste, crime, and sanitation data, to support the numerically small staff of the Chicago Department of Public Health (CDPH) in prioritizing food inspections to be carried out [143]. The model works by ranking restaurants by the probability that they have a critical food safety violation. The head of the CDPH, through a simple Shiny web application [144], is able to assign food inspectors first to the highest-risk restaurants. By using this model, potential foodborne illnesses could be prevented or their severity limited, as the violations were identified and treated earlier with respect to what would have been possible with previous selection methods.

- **Data Governance**. In addition to the aspects of data governance regarding Smart Cities, Barcelona has adopted a series of new standards, technologies, and practices, which have inevitably enabled new ways of managing data by different stakeholders [17], [96], with the result of increasing transparency, simplicity and objectivity, thereby providing a route to technological and data sovereignty. This has been achieved through the appropriate use of procurement clauses, e.g., contracts. The interested reader can find the Barcelona ICT Procurement Guide in [145]. In particular, and in regard to data, a minimum set of requirements are mentioned in regard to availability, accessibility, privacy-compliance, and shareability as Open Data among the various City Departments. In particular, they ensure that decisions around who produces, owns and exploits the data generated in the City remain in public hands. Those procurement guidelines are useful case studies for other Cities [96]. Although Barcelona is a successful case in this area, it is to be mentioned that innovative and effective public procurements involving digital systems in the PA may be challenging [146].
  It is not sufficiently clear how some aspects of data governance have been handled in Chicago, but in the blog of the Open Data Portal Development Team of the City [147], the process of data collection and accountability is documented specifically for the different types of data collected. The City of Chicago prioritizes personal privacy in the development of datasets for publication. For example, for the Taxi and Transportation Network Provider Trips (TNP or ''ride-share'') datasets, an anonymization and aggregation technique has been designed and implemented to reduce the risk of passenger re-identification, while enabling favourable public use of the data (see [148] for further details).

- **Inclusive Responsiveness**
  - **Skills and Co-Creation**. In October 2016, the Barcelona City Council, with an allocation of 75 million EUR to be spent annually on DT, planned to provide public services through an approach based on free software, Open Data sovereignty, and the adoption of Agile development methods, as discussed in [17].
    The main challenges addressed in their DT plans give rise to several initiatives as follows. First, the launch of an educational programme (Steam Barcelona), focusing on building competencies within city organizations, with the aim of strengthening the digital skills of the citizens. Second, the combined utilization of iterative and Agile development methods, for reducing the burden on citizens to use services (City empowerment). Third, the design and deployment of new guidelines on the design and accessibility of public services.
    With reference to [52], regarding the City of Chicago, the relationship between OGD and co-creation is addressed, in relation to factors that play a role in the co-creation component of OGD-driven public services. The result is the identification of a set of key factors for OGD-driven co-creation. Specifically: motivated stakeholders, innovative leaders, proper communication, existing OGD portal, external funding, and Agile development. The interested reader is referred to [52] for further details regarding those factors, since we limit ourselves to discuss Agile development within the **Organizational Responsiveness** below.
    There are also some lessons to be learned from this study. In fact, the authors also reported the main barriers to the publication and reuse of OGD, such as the widespread lack of understanding of OGD and their benefits. One of the main challenges to the co-creation of public services is the need to redefine the roles of public and private actors in the public service creation process. Some other barriers are connected to the figure of the citizen, such as the internal motivation of participants, personal characteristics, awareness of participation opportunities and participatory skills, perceived ability to participate in co-creation initiatives, trust in co-creation initiatives, the relative importance of the service to be co-created and mutual trust between Government and citizens.

  - **Leadership**. There are many facets to this topic. Barcelona exemplifies one of them. Specifically, the establishment of a managerial figure such as the Chief Technology and Digital Innovation Officer, to support the city's administration, thanks to which a series of politically and managerially strong reforms could be initiated [96]. Chicago exemplifies another one. Specifically: technologies, e.g., data analysis techniques that allow better leadership because they support decision-making processes, aiding managers in exploring and solving

some of the most difficult problems facing the city [52].

- **Organizational Responsiveness**
  - **Change Management**.
    The City of Barcelona, in 2017, within its DT transformation plans, has provided guidelines for project management that recommend the use of Agile methodologies [17], [96]. As a matter of fact, Barcelona has developed its own Agile methodology as a variation of the SCRUM Framework, referred to as SCRUM@IMI since the Institut Municipal d'Informàtica has had a major role in the adaptation of SCRUM to the Barcelona ICT needs. The interested reader can find a detailed account of this initiative at [149].
    As for Chicago, in terms of Agile development [52], according to the opinion of several interviewed stakeholders involved in the development of many projects, although the implementation of services did not explicitly follow Agile development methodologies, many of the characteristics of such approaches were however present in the development of services. The interviewees have emphasized some of these characteristics, considering them crucial to the success of the project, in the design, implementation, and service delivery phases. Namely, speed of development; release of a minimum viable product (MVP); validated learning; incremental development; constant testing; and the ability to respond quickly to feedback and evaluations.
  - **Frameworks and Maturity Models**. The Barcelona City Council has continuously collected feedback and, in terms of metrics, measured various performance indicators on the services provided in order to monitor signs of progress on the expected results of the adopted DT strategy [17]. It is not clear how progress on the expected outcomes of the initiatives implemented in the City of Chicago is measured, as we found no authoritative documents on this topic.

IV. DATA

We discuss here, in detail, the data ecosystem.

A. A GLOSSARY OF THE DATA ECOSYSTEM

For the convenience of the reader, we describe the following well known general terms: Open Data, Linked Data, and Linked Open Data.

- Open Data are accessible, exploitable, modifiable, shareable by anyone for any purpose, including commercial purposes, and released under an open license [12].
- Linked Data are structured in such a way as to be interconnected with other data sources to become more useful, promoting discoverability and interoperability. They are built on standard Web technologies such as HTTP, RDF, and URI, but instead of using them only to serve web pages to human readers, they are as well used to share information in a machine-readable way [150]. This type of data has evolved to encode and model knowledge coming from different sources. A notable example are the RDF Knowledge Graphs [151] and related ontologies, built on Open Data, that formally model domains of interest.
- Linked Open Data are the intersection of the previous two categories.

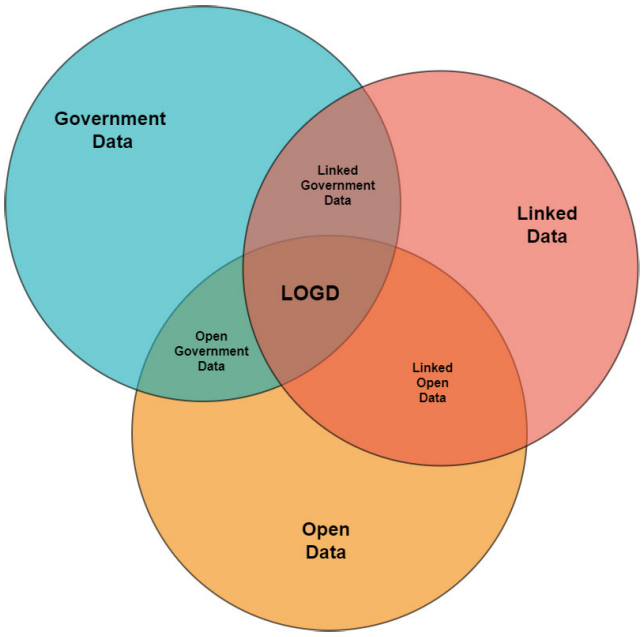

FIGURE 3. Relationships between government, open, and linked data (LOGD is Linked Open Government Data). Adapted from [15].

Government data is any information, in any form, that is created or obtained by the Government in the course of its business. When the data are public, we distinguish Open Government Data (OGD), Linked Government Data, and Linked Open Government Data (LOGD), respectively. Figure 3 represents the relationships among Government Data, Open Data, and Linked Data [15]. (Linked) Open Government Data make easier for citizens, researchers, developers, and businesses to access and use the data to create new applications, analyze social and policy trends, and develop transparency and accountability.

B. COLLECTION AND MANAGEMENT OF OPEN DATA: PAs ARE SPECIAL

Many of the data that we have described are represented using technologies related to the Semantic Web [152], via Open Data standards, which are defined by the W3C and supported by most technology providers, especially those offering data management tools. However, the collection and management of Open Data by a PA seems to require innovation in the processes adopted to carry out those tasks [153]. In the mentioned study, such an innovation is characterized in terms

of Agile methodologies: the ability of an organization to capture emerging needs and promptly associate them to the current data processes, in order to obtain innovative data-driven products and services. Based on the empirical study of four PAs, a process model for the achievement of the mentioned agility, is proposed (see [153] for details).

Improving the usability of some collected data also requires innovation. Indeed, as discussed in [154], although there is a proliferation of Open Data platforms, their usability for the non-specialist is perceived as poor, mainly due to the fact that they have been designed by software specialists. The mentioned study also provides the evaluation of the usability of an Open Data platform by non-specialists, for the City of Dublin, pointing out the need for innovative designs of user interfaces. Open Data integration is also a serious obstacle to their fruitful use, with some proposals on how to overcome them, accounting for implementation strategies and organizational models [155].

C. FROM A DATA ECOSYSTEM ABSTRACTION TO ITS CONCRETE REALIZATION: SOME EXAMPLES

Figure 3 provides a general description of a data ecosystem, which can then be realised in several ways, that should be compliant with the Open Standards defined by the W3C [135]. Two incarnations of a data ecosystem have already been presented and discussed in Section III-D: the Barcelona CityOS data lake and the Chicago Open Data portal. We now provide three additional examples, concentrating on their technical aspects and pointing out their usefulness.

- **Open Data Catalogs for the PA**. They are software applications that build inventories of data resources of a given PA, in order to help data professionals and stakeholders to find relevant data for analysis-related uses [156]. They are based on metadata, which provide additional data/information about data resources. The intent is to help catalogue users to understand the structure, nature and context of the data available in computer systems and decide whether they are suitable for their needs. One of the earliest relevant examples of an Open Data Catalog proposal is the OGD Catalog of the Czech Republic: it serves as a single access point to the OGD datasets, supporting the discoverability and reusability of the available OGDs. Another, more recent example, is provided in a case study of the Italian PA [33], conducted during the period April-December 2017, in which the use of the OGDs favour the implementation and integration of services (or digital platforms) such as pagoPA (payments system to PAs and public service providers in Italy), SPID (Italian Public Digital Identity System), and ANPR (Italian Register of Resident Population). These new services are based on OGD Catalogs, and in addition to the use of Open Standards, and Open Software, are designed as modular structures, which facilitate their evolution and reduce the complexity of coordination between the actors involved in the co-creation processes of the various projects, as also as reported in [112] and [61].
  For a successful integration of services, a good interoperability framework of information sources must be provided. In general, it organises the exchange of data and interoperability between different services, data centers and PAs. It consists of a set of specific design rules, documents and toolkits for software developers (e.g. Software Development Toolkits).
  For the specific case study, the main part of the interoperability framework is the Data Analytics Framework (DAF), which collects and processes data from PAs and external actors to make them publicly available and accessible through a Web user interface, and defines protocols and regulations that facilitate the integration and orchestration of services. The DAF empowers each PA to orchestrate the creation of public value by establishing the actors that can have access to the data and the terms under which they can access them. Uploaded data are supervised by the Data Protection Authority [157], which safeguards the privacy of citizens and evaluates how other public agencies use their data. Therefore, each level of government and the different public agencies are responsible for regulating how data is accessed, according to their administrative and political responsibilities.
  Specifically, a PA, as well as a private company, can make data available to the public through the DAF, and can also indicate who can access that data and the ecosystem on which that data should operate. As expectations and needs change, data access settings can be modified to adapt to emerging needs and requirements. When public agencies upload their data to the DAF, they fill out a privacy form to ensure that the data is privacy compliant, so as to avoid any negative effects on citizen privacy.
- **Cloud-based Open Data Federation: the CLIPS experience** [16]. CLIPS is a cloud-based approach for migrating public services to the Cloud, based on the use of microservices. It involves four European Cities: Bremerhaven (Germany), Lecce (Italy), Novisad (Serbia) and Santander (Spain). It is based on the Open Data because, in addition to being a useful resource for developing new value-added services, they seem to be valuable for exploring potential transnational business opportunities. The CLIPS platform includes an Open Data Federation node to allow access to the Open Data sets from different federated Municipalities, as if they were a single data source for front-end applications. The main innovation of CLIPS is to provide a usable methodology, that enables Government employees and other external stakeholders to collaborate on new projects and service delivery from a set of basic building blocks, available in the Cloud. This offers the ability to respond more quickly, reduce service delivery costs

and be more responsive to end-user needs. It defines an approach for building an ecosystem in which PAs, small and medium-size enterprises, and citizens can co-create new and innovative public utility services. The CLIPS platform is designed as a three-tier cloud platform, including: an Infrastructure-as-a-service (IaaS) which includes all the required modules to provide basic cloud resources like computation, storage and networking; an application serving and development functionality of traditional Platform-as-a-service (PaaS); and a convenient marketplace for the developed cloud-based services and microservices, typical of a Software-as-a-service (SaaS). It consists of several modules, such as authorization, authentication, and monitoring of data access, as well as providing an API to connect the microservices present with each other. Data security aspects are also addressed. In fact, the CLIPS Security strategy, in addition to common security best practices (e.g., ISO/IEC 27002, ISO/IEC 27017, ISO/IEC 27018), is to adopt some innovative techniques and approaches from the open-source community as well as from other European Projects, such as "Secure idenTity acrOss boRders linKed" (STORK) [158], enabling citizens to use their national credentials in PA applications provided by foreign States and to securely transfer their sensitive data between the States.

- **Data and Smart Cities**. Smart Cities are perceived as data engines [83], [159], e.g., IoT infrastructures, social networks, wearable devices, etc. generate valuable data that can be used to improve or offer new services to the citizens. However, due to its volume and heterogeneity, the collection of data produced by Smart Cities (including the creation of related metadata) requires a non-trivial effort in the verification of its correctness and quality [159]. Metadata can describe different information sources and can be collected and catalogued within appropriate Open Data Catalogs, such as the open-source solution already mentioned CKAN. Moreover, metadata can be represented through data vocabularies designed to facilitate interoperability between Open Data sources available on the Web, e.g., using the DCAT-AP metadata profile [160]. Fundamental turns out to be the implementation of a set of guidelines and documents such as API documentation, and planning documents, systematically discussed and agreed upon with public officials responsible for providing datasets to improve discoverability, understandability, and further processing of data. As shown in [161], the implementation of these solutions involves a careful design phase of the technology infrastructure (cloud/edge) related to Smart Cities, with an emphasis on the data acquisition plan. The infrastructure must be the pillar of processing and storage of data and also include data analytic tools and methods finalized to the implementation of robust machine intelligence solutions available to the city government for the benefit of its citizens. To this end, three distinct taxonomies of data analytic tools serving Smart Cities are proposed in [83] and referred to as the DMS Taxonomy, i.e., data, methods and services.

V. TECHNOLOGY

We discuss here, in detail, the two main technical aspects we have considered concerning **Technology**: Smart Cities and data governance. As anticipated in Section III-C, for Smart Cities, we concentrate on Digital Twins. It is useful to remind the growing importance of AI and blockchain techniques for the DT. In particular in regard to Smart Cities, we point out that, when discussing Barcelona and Chicago, we have provided two examples of such an important role within those Smart Cities (see relevant section). Indeed, Barcelona uses the blockchain technology of the EU DECODE project to handle data access granting privacy, while Chicago uses machine learning techniques to perform sanitary controls and disease prevention.

A. SMART CITIES: DIGITAL TWINS

Being specific to Smart Cities and following [97], the major characteristics of Digital Twins are: accurate City Mapping, for instance, of roads and public illumination; interaction between the virtual and real "objects", e.g., people and their "avatars"; software definition, e.g., platforms that simulate the real city in a virtual space; intelligent feedback, e.g., evaluation of the effects of city plans and initiatives before realization. Interestingly, it has been argued that their realization may enable an acceleration of NetZero emissions in government critical infrastructures [162]. A further refinement of the technical characteristics of Digital Twins is proposed in [163], although its major contribution seems to be the account of Digital Twins initiatives in China, USA, and France.

Although there are many national and city initiatives regarding Digital Twins, e.g., [164], [165], [166], and [163], we have found only a limited number of academic papers covering the subject. One is in regard to cross-border Smart Cities, i.e., Helsinki and Tallinn. Recalling that an urban operating system is a network of sensors that can acquire data regarding the city which, in turn, can be transformed into "knowledge" [167] and pointing out that the X-Road data infrastructure [168] is one of the pillars of Estonian DT, a cross-border urban operating system involving both cities is proposed in [169]. The intent is to have an integration of the DT that is involving only each of the mentioned cities. For completeness as well as relevancy for this Tutorial, we mention that the notion of urban operating system is investigated in depth in [170], with various examples of it. The study points out the modest impact that it may have on city planning and its contradictions.

Overall, Digital Twins have the potential to bring significant benefits to Smart Cities, including better evaluation of

city plans, and potentially even achieving NetZero emissions, but further research is needed to fully understand their impact.

B. DATA GOVERNANCE

In the context of our Tutorial, we focus on two particular aspects of data governance, i.e., privacy and cyber-security.

In terms of privacy, in the international scenario, there are several National Data Protection Authorities. An exhaustive list of these Authorities can be found through an interactive map on the website of the French National Commission for Information Technology and Civil Liberties (CNIL) [171]. The main function of the individual Authorities is to protect the privacy of citizens and assess how the PAs (or other organizations) use their data, for example, by keeping under control the data they publish on their respective institutional web portals. Barcelona is a good example in terms of control of the data, regarding availability and detail of access, as discussed in Section III-D. As well argued in [172], the amount of data that is collected within Smart Cities initiatives, once made public, even in an anonymous form, can be subject to cross-reference attacks that could capture private information. In order to address this problem, the mentioned paper proposes solutions and use-cases. Interestingly, that study is a pilot project funded by the U.S. Department of Homeland Security that has the intent to demonstrate how data privacy technologies can be of help.

In terms of cyber-security, it is well known that there is a proliferation of Cyber-Security Agencies, e.g., the European Union Agency for Cyber-Security (ENISA) [173]. This is not surprising, given the increase in the number and quality of the attacks of which we have news in the past few years [174]. However, since PAs are also the object of those attacks, it is surprising that there is only a limited number of papers that have emerged from the literature regarding DT that address cyber-security issues, as we outline next.

With regards to data, in [24], the Organisation for Economic Co-operation and Development (OECD) [175] recommends maintaining a strong balance between the need to provide timely official data and the need to provide reliable data, as well as to manage the risks associated with the increased availability of data in open formats and those related to digital security and privacy. A related issue is the design and management of government data centers architectures, in particular regarding security. Indeed, those centers, due to the heterogeneous nature of services they offer and software they host, are vulnerable from the point of view of security. A proposal on how to achieve ISO/IEC 27000 security standard, a model of government data centers architecture, has been proposed in [176]. More in general, as discussed in [177], there are several initiatives in many countries having the goal to provide methodologies for security assessment. This latter consists of evaluating an information system from the attacker's point of view, with the aim to provide a systematic review of weaknesses in information systems, with a corresponding assignment of probabilities of attack via each weakness, offering also a scale of severity levels of damages. Recommendations for corrections are also offered.

Smart Cities and their associated technologies, being relatively novel, are also object of study in terms of security. A specific analysis regarding IoT devices and related technological infrastructures, is given in [19] (but see also [178] and references therein). Indeed, due to their interconnected nature, IoT technologies make data security a more complex challenge with respect to the past. Therefore, ensuring the security of IoT products and services has become a top priority. To this end, an entire framework, referred to as SAO, regarding the automation of IoT security has been proposed in [178]. It has the merit of being grounded on a recent review of the State of the Art, clearly describing challenges and proposing solutions. SAO integrates the key elements for security automation and orchestration for IoT systems, including threat modeling, security and privacy by design, trust management, security configuration, threat monitoring, patching, compliance check, and secure data sharing. Another specific analysis is provided in [179], regarding Digital Twins. Indeed, the confluence of a broad set of technologies, ranging from cyber-physical systems to artificial intelligence, and the implicit interaction with the real objects modeled by the Digital Twin, poses new security threats. The mentioned paper offers a classification of them, together with security recommendations on how to address them, via a paradigm that classifies the threats based on the functionality levels composing a Digital Twin.

VI. PEOPLE

We discuss here, in detail, the technical aspect we have found concerning **People** that deserves further attention, based on the Literature search: Skills and Co-Creation.

A. SKILLS AND CO-CREATION

A successful DT process requires users not only to acquire new skills but also to know how to interact effectively with them [60], [61]. Those skills required to handle DT do not only relate to a particular discipline but require a multidisciplinary approach, where the importance of knowing the specific competency levels of the individuals that are part of an organisation and the know-how of the entire organisation itself is recognised as a fundamental requirement. The lack of a coherent educational approach to the acquisition of appropriate skills also hurts e-government users, which could generate problems in the usability of the PAs digital services [32]. In [61], the authors, as a possible solution to this shortcoming, propose an educational framework composed of five basic components designed, developed, and tested to achieve the educational goals necessary for a successful DT strategy. The components of the framework were intended to define: (a) a competency model useful to describe the required competencies; (b) an educational approach that can be provided by the professional or academic context; (c)

a maturity model to monitor progress in the process of acquisition of the required competencies; (d) an appropriate didactic model that is tailored to digital capabilities and demands is essential in order to make competence delivery successful and efficient; and (e) a competency certification system to coach organizations and citizens to understand and communicate their competencies, ensuring transparency and quality.

As for co-creation, it is useful to recall from the previous sections that the ultimate goal of a digital PA is the co-design and deployment of services that are perceived as being of "value" (see **People** in Section III-A). Accordingly, how to achieve that goal and with which methodologies and supporting technologies is an emerging area of research [34], that we outline next.

In its simplest and easiest to realize form, a co-creation methodology is limited to the participation of a strictly selected set of users, particularly in the initial phase of the creation process, and to the related measurement of their perceived satisfaction degree, through constant feedback collection [57]. However, the intent is to have co-creation methodologies that can handle millions of users, i.e., citizens. It is natural, then, that the IT platforms supporting the PA must support those "in the Large" co-creation methodologies. Recalling from [33] that Government as a Platform (GaaP) is a new way of building digital public services using a collaborative development model by a community of partners, providers and citizens to share and enhance digital public processes and capabilities, or to extend them for the benefit of Society, its realizations seem to be designed to achieve efficiency. However, according to the mentioned study, the efficiency granted by GaaP does not necessarily imply the creation of value for the citizens, a point also made in [56] and [10]. Indeed, as discussed in the mentioned paper, the key to the creation of public value seems to be the modularity of the platform configuration and the ability to consistently coordinate different ecosystems that support public agencies. To this end, a few examples are provided, borrowed from the private sector and involving IT giants such as Apple, Google and Amazon. Here we limit ourselves to mention the Apple iOS Support Service [180], which enables multiple ecosystems, different in nature, to interact and coexist. According to the analysis reported in [33], the adoption of analogous models would allow the co-creation (PAs and citizens) of value services with a "large scale" involvement of active actors. The importance of adequate digital platforms for the co-creation of value involving a large number of actors is also identified as a key success factor in [57]. A paradigm shift from crowd-sourcing and social media monitoring to IoT has also been proposed, with a pilot project that has been set-up in a Municipality in Sweden [181].

In addition to what we have mentioned so far, the notion of participatory design, e.g., the involvement of citizens in urban planning, is being analyzed in view of DT. A historic account of how that notion has changed over the decades and how it fits a modern view of DT is provided in [182]. An important related topic is the co-creation of integrated public services. That is, ideally, a one-stop platform for the citizens that integrates the available services to them. The State of the Art, mostly regarding EU, is well presented in [183].

For completeness, we also mention that, in terms of PAs and co-creation of value, the Italian public administration as a platform is studied in [33]; the Norwegian Labour and Welfare Department is studied in [57], while a platform supporting co-creation at different levels of governance in Portugal is presented in [184]. A specific platform for co-creation in the area of Urban Planning and in support of previous initiatives, i.e., the International Laboratory of Architecture and Urban Design, has been proposed in [185]. Finally, a model based on Digital Twins that allows co-creation, as well as evaluation of the final result regarding public services has been proposed in [186], with a planned test of the model in Sofia.

VII. PROCESS

We discuss here, in detail, the two main technical aspects we have found concerning **Process**: Change Management and Frameworks and Maturity Models.

A. CHANGE MANAGEMENT

As well put in [149], although the Agile Manifesto dates back to 2001 and despite the remarkable success that the corresponding methodologies have had in the private sector, their adoption in the PA is rather slow. Yet, in the DT, Agile project management methodologies (see [187]) seem to be the ones that should replace more classic ones, such as Waterfall [188]. In order to exemplify this point, the experience reported in [189] and [190] suffices. In the mentioned studies, the authors point out that the implementation of the e-governance project Digital India Land Records Modernization Program (DILRMP) has highlighted major challenges and complexities, typical of traditional project management. They discuss how an Agile management approach can play a key role in transforming such implementation from slow and ineffective to be more responsive, flexible and effective.

Documented difficulties in the adoption of Agile methodologies have emerged [59], [63], [117], [118], [191], [192]. The cause is common: the difference in modus operandi between the PAs and the private sector, resulting in resilience to change, and difficulty in identifying the most appropriate methodologies for the PA. Fortunately, studies [193] seem to have identified "agility enables", i.e., possible actions that can facilitate the transition to Agile models. However, as pointed out in [194], the transition to Agile development models will require the writing of appropriate guidelines to be used to ensure that the development process is Agile. These will depend on the particular requirements of the organization involved in the transition process.

Although the highlighted difficulties persist, there are many PA project management initiatives that use the Agile methodologies, e.g., in the software development Census of the Swedish Government Agencies, the majority of Government Agencies consider their approach to be more Agile than planned [195], [196]. In addition to Barcelona and Chicago, mentioned in Section III-D, the Agile methodologies are applied in several PAs [17], [149], ranging from National (e.g. UK), Large Cities (e.g. New York), and Regional Governments (e.g. Andalusia). Apart from the above noteworthy examples, a systematic and technical presentation of the adoption of Agile methodologies for project management in the PA is reported in [62]. The paper makes also a list of the Agile process automation technologies that are in use, i.e., Scrum, Kanban, and SAFe (see again [187]). A comparison is also performed with classic Waterfall methodologies and it is stated that the Agile ones allow for more transparent projects, effective team building, adaptability to change, lack of hierarchy, lack of bureaucracy, and continuous education. Some disadvantages are also reported, such as: the risk of endless product changes; the high dependence on the qualification and experience level of the development team; the difficulty of determining total project costs in a timely manner. Although unclear in its impact, an effort is also made for the identification of the specific characteristics that the Agile methodology should have for its use in the public sector [64]. The mentioned paper reinforces the difficulties already mentioned and that must be overcome for such a change of project management. Moreover, it stresses that project management should be reconfigured to provide team autonomy, to some extend. Once again, the barrier being routine practices difficult to abandon and obsolete regulations.

A more specific evaluation of Agile methodologies in the PA, regarding DevOps [197], is provided in [67] and [198], where it is considered how to bring best practices from the production world into PA, making the flow of information more fluid. As a result, the adoption of DevOps promotes organizational responsiveness, which is useful for improving productivity and performance. At the same time, DevOps breaks down organizational barriers by promoting information exchange through the use of shared metrics and feedback mechanisms between development teams, as reported in [199].

By bringing DevOps into the public sector, an effective teamwork and a consequent open flow of knowledge among PA employees are expected [200], [201]. There are initiatives in this regard, as for instance the ones of the Brazilian Federal Government, referred to as Brazilian Public Software (SPB). The objective is to promote sharing and collaboration enabled by Free/Libre/Open Source Software (FLOSS) solutions for PA [200]. SPB is an interconnected platform based on different FLOSS tools that provides different solutions for collaborative software development, with the purpose of enabling Brazilian PAs to share information, experiences, and best practices about the use of these tools (see [202] for more details about the architecture and operational manuals).

Furthermore, since transparency and openness are among the core principles of DevOps practices, their use is expected to simplify bureaucracy and decrease corruption in public service delivery. A punctual analysis regarding the benefits of using the DevOps Process Model in the PA is presented in [203]. It involves seven Saudi Arabia PAs, evaluated with the use of the Bucena DevOps Maturity Model [204]. That study concludes that the use of DevOps is promising although DevOps cultural aspects, process, and technologies need to be strengthened. An additional study proposing DevOps for the generic support of Digital Transformation is presented in [205], being in agreement with the papers mentioned so far.

We mention that there are also experiences indicating that classic Waterfall and Agile methodologies can synergically co-exist. Indeed, we learn from the case study in [66], involving the development of projects through Agile methodologies of some Brazilian governmental organizations, that although the adoption of such methodologies fosters an improvement in the quality of the public services created, these projects achieve greater success when conducted in combination with other traditional software development approaches.

Finally, Agile software development in the public sector must be scalable, i.e., able to work for relatively small projects, coming from small realities such as cities, to large national and international projects, for example through the adoption of the SAFe Agile process automation technology, as reported in [206] and [115]. To this end, it is of interest to mention a recent review [207] regarding the use of Agile methodologies on a large scale. Although one would expect that the PA would be the area with the most involvement, it is somewhat disappointing to report that only 5% of the initiatives reported there belong to the public sector.

B. FRAMEWORKS AND MATURITY MODELS

Over the past decade, various frameworks and models have been developed to measure and monitor the degree of digital maturity achieved by Digital Transformation Strategies. To date, however, it is not possible to choose one among them for which any organizational reality can be perfectly modelled, whether private or public. Each of these captures a particular set of indicators and uses different tools to collect information to be used to quantify the indicators. One of the tools is certainly interviews, with the possible addition of document analysis [33], [58], [65], [66], [72], [76], [111], [123], [208], [209], [210], [211], [212], [213], [214], [215]. In the mentioned case studies, semi-structured interviews are mainly conducted with various IT professionals from public and private organizations, actively involved in DT processes, over different periods in order to measure the degree of digital maturity gained. Several barriers and success factors emerged from the interviews, which are useful for a

comprehensive understanding of DT. The results show that this survey instrument is quite valid, as effectively reported in [76], [214], and [58] (see respective Appendix Sections).

In addition to the model specific to interviews, many general maturity models have been developed over time. For most of them, based on variables specifying the model, the ''end-result'' is the value of an index that assesses the level of achieved maturity. Some follow macro-economic factors on a national or international level, as in [69], [216], [217], [218], [219], [220], [221], [222], [223], and [224]. Others, however, refer to micro-economic factors related to individual organizations, as in [124], [204], [225], and [226], [227].

In regard to the first group, we discuss only the GovTech Maturity Index (GTMI) developed by the World Bank [69], as part of their GovTech initiative (Government and Technology) [228], since it appears to be the most exhaustive maturity model currently available. It is worth pointing out that GovTech is an approach to the modernization of the public sector, through innovative technological solutions, that promotes a simple, efficient, and transparent Administration with the citizens at the center of the reforms. There are about 80 GovTech initiatives worldwide, with good practices observable in 43 countries out of the 198 observed. In this context, GTMI is a comprehensive measure of the DT in a given country. It is based on 48 key indicators and it is defined to collect data from 198 countries. GTMI measures key aspects of four focus areas of the GovTech initiative: supporting Core Government Systems (CGSI, 15 indicators), improving Service Delivery (PSDI, 6 indicators), Engaging citizens (CEI, 12 indicators), and promoting the Enabling factors of the GovTech initiative, such as building digital skills in the public sector and an environment conducive to innovation in the public sector (GTEI, 15 indicators). Each of the indicators is associated with a certain score and a certain weight, the latter based on the opinions of some domain experts on the relative importance of the selected indicator. Using these scores and weights, the CGSI, PSDI, CEI, and GTEI scores are calculated. The final GTMI score, on a [0, 1] scale, is calculated as the arithmetic mean of the four scores just mentioned. See [69] for more explanatory details on the indicators. All 198 countries were grouped into four categories: from A (leaders in GovTech) to D (minimal attention in GovTech) according to their GTMI score.

Based on analyses comparing the GTMI with other relevant indices, the GTMI indicators were found to be consistent and robust, even concerning the analysis of lesser-known dimensions related to particular characteristics of a given Government. Results and good practices presented in [69] demonstrate how the GovTech focus areas identified by the World Bank are highly relevant to the DT agenda in most countries.

As for the second group of models, which relates to the micro-economic factors of individual organizations. For conciseness, we will only briefly discuss the Digital Maturity Balance Model [124]. It is oriented towards PAs and is based on two axes: digital maturity and importance ratio. The focus is on measuring the balance between the two. Each maturity dimension is assessed by taking into account the importance ratio of this dimension in the Organization. The main categories of maturity dimensions involved are data, IT governance, strategy, organisation, and process. The construction of the model essentially consists of three steps. First, a method must be defined to assess digital maturity. Secondly, a method must be defined to measure the importance of each dimension of digital maturity pertaining to each of the categories involved. Third, a self-assessment tool must be provided that combines the methods just mentioned, e.g., in the form of an online questionnaire, in which the questions allow the assessment of the digital maturity criteria and the digital relationship attributes. Results show that the use of the model and of the self-assessment tool is useful and relevant, but needs further refinement to fully correspond to the reality of a given PA.

Interestingly, micro-economic maturity indexes may be of use in measuring other aspects of DT, far from the ones they have been designed for. By way of example, the CMMI index [225] has been adapted in [229] in order to measure the success of the adoption of the Agile DevOps methodology in the PA project management.

From the presentation above, it is clear that many indexes and maturity models exist for evaluating the DT progress of an organization. However, they can be limiting because they tend to favour a sequential, linear approach to digital growth, leaving out the intricacy and flexibility needed in an ever-changing organizational environment, as in the case of the PAs. In addition, they may not fully account for the unique challenges of each organization, as they are often standardized and not always adaptable to the specific needs of individual organization contexts.

VIII. FUTURE DIRECTIONS

- **Data**

  From what has been discussed in Section IV, it is evident that data innovations come from using Open Semantic Web standards in the context of PA to represent their information assets. The introduction and use of Open Data is certainly a big step forward since the advanced functionalities they make available have transformed the OGD landscape [230]. Apparently, little attention has been dedicated to the LOGD, in particular, to all those activities related to the production and maintenance of quality levels, which facilitate interoperability with other data sources [15], according to the Open Government principles [231], [232]. In particular, a domain that needs attention for the DT is the one regarding the use of RDF Knowledge Graphs, since their use would facilitate the discovery of new data sources and improve their interoperability among different PAs. Another aspect that needs to be developed is to set-up mechanisms that strengthen the trust among citizens and PAs regarding the use of the collected data [10]. A related topic is

security, in particular regarding the creation of a system of protection balancing the needs of PAs and the risks connected to Open Data and interoperability.

- **Technology**
  As outlined in Section III, Cloud Computing is a main component of any DT. Moreover, as discussed in Section V-A, the diffusion of Smart Cities and Digital Twins are very promising. Somewhat unfortunately, the complexities related to their full-scale realization are far from being addressed and resolved. The difficulties of scaling are best exemplified by a study regarding energy consumption optimization of "only" sixteen buildings in Rome, via Digital Twins [233]. A recent review clearly outlines the five major challenges that need to be addressed [234]. Not surprisingly, they range from data collection, storage and analysis to computing power. Although some research directions are also mentioned, they lack specificity and a clear assessment of how the scale of what has to be managed via Digital Twins affects costs: a city, even a major one, may not be able to economically sustain its full fledged Digital Twin.
  Concerning privacy and security, the adoption of recognized standards, such as ISO/IEC 27001 is strongly recommended, as indicated in [16] and [176]. To this end, it is suggested that a more collaborative approach be taken to support security in developing effective and appropriate solutions to security challenges, including increased efforts on technologies IoT [19], to prevent attacks or minimize their effects. At the State of the Art, there are no evident documented outcomes in the Literature on how these recommendations have been understood and pursued by the PAs. The actions, however, appear to be in place, as shown in the timelines of the NRRP Plans, i.e., [235].
- **People**
  One of the major problems that emerge in terms of digital skills is the necessity of proper educational efforts, such as courses and tutorials, in particular in developing countries [61]. In summary, the development of a digital education ecosystem is one of the major needs for an effective DT. By way of example, actions in this direction are planned in Europe [236] and recommendations are given in the U.S. [237]. In terms of co-creation, its widespread adoption within PAs requires relevant structural changes, including a sourcing strategy, a governance structure, and a more flexible digital infrastructure, as reported in [57].
- **Process**
  It is clear from Sections III and VII that the way in which projects are designed, managed and implemented must change in order to achieve an effective DT. Agile technologies are one technical way of realizing such a change. However, the DT is a dynamic process that may generate the need for "new and higher transformations" that may impact the mission of an organization. For instance, the IT department of a large Finnish municipality, transformed its mission from problem-solving to proactive service delivery, partly through a collaborative approach with business units, as reported in [72]. Therefore, Agile technologies may well be the "tools", but a clear plan of what is DT is essential. Such a plan and vision may change depending on the scale (local, regional, national), although some coherence among the various levels of the scale must be ensured. To the best of our knowledge, a DT approach that accounts for the granularity and hierarchy of the components involved is not present. It is to be said that Agile technologies reinforce the need for capacity-development of stakeholders [77], i.e., the acquisitions of digital skills. Moreover, although more collaborative project management approaches are felt as necessary with the goal of interoperability, the lack of agreed processes, the difficulties of interpreting administrative and legislative procedures, and the difficulty of defining authorities and responsibilities are just some of the reasons why interoperability between PAs is not achieved, as outlined in [18]. Again, solutions to this problem are related to the scale at which we look at DT: interoperability may be simple to achieve in a restricted and uniform community and much more difficult in larger and more heterogeneous ones.
  As for indexes and maturity models, as outlined earlier in the relevant section, they have limits. In particular in regard to their scalability, e.g., a model that works well on a national scale may be too coarse to be applied to a local organization. Although it is quite complex to have a universal maturity model, an effort has to be made in order to devise models flexible enough to scale well with the complexity of the organizations where they are supposed to be used. Possibly, hierarchical maturity models could be a promising avenue of research.

IX. CONCLUSION

This Tutorial presents a guided tour of the main areas of the DT of the public sector from the perspective of a computer scientist. We started from an analysis of the literature on Digital Transformation available on some digital libraries well known to computer scientists. Using the query described in Section II we found almost six thousands of papers related to Digital Transformation, that were reduced to the papers listed in the references that we have used as the basis for this Tutorial. Our study has identified the critical factors of a successful DT, and the challenges in the areas of data, technologies, people and processes which have been faced by some public administrations in different countries. We believe we have given an original synthesis of some problems and their solutions, useful for understanding the main topics underlying efforts of digitally transforming the life of citizens by some public administrations. Our findings suggest some future directions for research and practice in the four areas mentioned, as discussed in Section VIII.

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