Managing urban infrastructure assets in the digital era: challenges of municipal digital transformation

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Abstract

Purpose – The purpose of this study is to frame digital transformation (DT) within municipalities to improve the life cycles of urban infrastructure.

Design/methodology/approach – The study provides the results from a systematic review of the literature on concepts of DT and its implications for municipalities, barriers and challenges to DT, as well existing DT frameworks for municipalities and their built assets. This literature review leads to the development of a DT framework to help cities conduct a planned and federated DT beforehand. Then, workshops are conducted with two major Canadian municipalities.

Findings – The results of these studies point to the need for a dedicated DT framework for municipalities because of their particular context and their role and proximity to citizens. The theoretical framework develops 22 elements, which are divided among 6 categories. Through its application, the framework helps to identify and target the predominant issues hindering the DT of municipalities, specifically "legacy practices" and "data management."

Research limitations/implications – Limitations include limited experimental conditions and small sample size. Further work is needed to validate the framework. Other approaches are advocated to complement the data collection and analysis to generate more convincing results.

Practical implications – The theoretical framework was validated through two case studies on two large Canadian municipalities.

Social implications – Municipalities maximize the value they provide to citizens and to be at the forefront of resilience and sustainability concerns. The use of technology, digital processes and initiatives helps cities to improve planning, optimize works and provide better services to citizens.

Originality/value – The framework is original in that it specifically aligns assets management with DT in a municipal context.

Keywords Digital transformation, Municipality/city, Government, Barriers and issues, Strategic and organizational framework

Paper type Research paper

1. Introduction

Municipalities face multiple challenges in maximizing the value they provide to and generates for their citizens. Moreover, they must contend with growing resilience and sustainability concerns. Recognizing these challenges, the United Nations (UN) has identified 17 sustainable development goals (SDGs) including, industry, innovation and infrastructures (no. 9), sustainable cities and communities (no. 11), and sustainable consumption and production (no. 12). Municipalities not only have to plan, deliver and maintain critical assets but are also responsible for the regulation and approval of all construction within its boundaries. Moreover, studies by the G20 Global Infrastructure Hub, the UN and McKinsey & Company confirm that the infrastructure financing gap is significant, amounting to

trillions of dollars per year (World bank blogs, 2022). The UN's 2020 report on financing sustainable development suggests accelerating long-term public investment in resilient infrastructure that contributes to sustainable development. It also provides policy options for harnessing the potential of digital technologies. Yet, achieving this requires operating significant, long-lasting change.

The digital transformation (DT) of the municipalities' planning, delivery, management practices as well as the optimization of its services to its citizens can help them achieve these goals (Shkabatur, 2010; Beaudet & Shearmur, 2019; Pereira, Luna-Reyes, & Gil-Garcia, 2020). Indeed, if well executed, through the implementation of digital tools and technologies supported through a reconfiguration of practices, DT can potentially help more effective decision-making through structured and accessible information. However, to achieve this, DT must be well planned, executed and managed, which is no small feat given that municipalities not only struggle to keep pace with the transformative changes needed to align their old practices, operations and emergency response with this new evolving digital age but also lack the necessary resources to do so (Mcgill, 2019; Divay, 2020).

DT in governmental and municipal settings consists in a fundamental change in business processes with the objective of creating more value for the community. DT is driven by the introduction and accessibility of new ideas and trends driven by novel information and communication technologies. As these are constantly evolving, DT must also evolve accordingly. More seminal concepts and paradigms, such as the "cyber city" (Scime, 1994), are being replaced by concepts such as "open government" (Mergel, 2015) or "governance in the digital age" (Roberge, Jamet, Nantel, Senneville, & Tchéhouali, 2019), "the digital city and the smart city" (Lafioune & St-Jacques, 2020) and the "digital twin" of a city (Shahat, Hyun, & Yeom, 2021).

Municipalities implement a variety of technology tools to benefit urban infrastructure asset (UIA) lifecycle activities for existing and to-be-constructed built assets, such as buildings, roads, railways, sewer and water systems. UIA management activities include project portfolio planning and management, construction project management, and the operation, maintenance and use of urban built assets. The aim of this massive use of technology is to structure and connect information more effectively, in order to facilitate decision-making for urban development planning. It also helps to optimize the use of existing urban infrastructures and improve the services offered to citizens, both present and future.

An increasing number of municipal authorities have started to experiment with several technologies, such as Geographic Information Systems (GIS) and Building Information Modeling (BIM). Nevertheless, a significant number of municipalities are experiencing difficulties in undertaking DT (Ringenson, Höjer, Kramers, & Viggedal, 2018), even though DT is progressing in many areas, including public infrastructure (Apraez & Lavrijssen, 2019). Although some UIA management activities are being reorganized at the municipal level through the implementation of various technologies (Proulx, 2005), but DT is essentially a strategic relocation of organizational activity (Bloomberg, 2018) and is not limited to technologies. It lacks a long-term vision and a holistic understanding of needs, barriers and challenges.

Moreover, municipalities appear to be undertaking DT in a haphazard and ad-hoc manner. Thus, there is indeed little theoretical underpinning to support DT for integrated UIA management within municipalities. Consequently, there is a need to frame DT and what it means for municipalities given their strategic importance. Current governance considerations do not take into account the core values specific to public organizations, such as public value (Broucker, De Wit, & Verhoeven, 2018), nor the federation of DT. Thus, municipalities also need help to better frame DT, its implications and address its challenges and obstacles to ensure its success. Although the issue of DT has been addressed in many areas, there is a lack of such investigation at the municipal level, particularly in relation to UIA management (AM).

The research presented in this paper is part of a longitudinal study on the DT to support integrated UIA planning, delivery, management and use within municipalities. This study focuses on the development and validation of a preliminary theoretical framework that aims to articulate the barriers and challenges that prevent successful DT from supporting lifecycle activities relating to UIAs in municipalities. Addressing the challenges and barriers laid out in the framework, namely by increasing a municipality's digital maturity, can help to transform the decision-making process and, consequently, the quality and promptness of service delivery to citizens. This research incites reflection as to how cities resolve to undertake DT but without prior planning or organizational frameworks. It demonstrates how a city's operational needs create pressure on its data management to initiate DT and how ad-hoc DT initiatives reinforces silos between departments. Therefore, the framework provided by this research will seek to mitigate and/or eliminate the issues that hinder successful DT.

The objectives of the research presented in this paper are: (1) to identify and categorize the barriers and challenges to DT for municipalities pertaining to the UIA domain, (2) to articulate these barriers and challenges within a framework and (3) to test and validate this framework as an input in the subsequent phases of the longitudinal research project.

To achieve this, a systematic literature review was performed,and a series of workshops were held with two large Canadian municipalities. The research presented in this paper thereby offers an investigation into the phenomenon of DT in the context of the public sector at the municipal level. The research discusses how a municipality can keep pace with technological developments while anchoring its day-to-day UIA lifecycle practices. This paper contributes to the literature on DT in municipalities to support the planning, delivery, management and use of municipal built assets or UIAs. The proposed framework articulates challenges that municipalities face in their DT. It also provides a guide and analytical tool for the DT of public organizations and demonstrates its potential application in practice.

The article begins with a review of the literature on the concepts of DT and its impact within the municipal domain, the barriers and challenges of DT, existing DT frameworks, and how public organizations are adapting to developments in the field of digitalization, as well as the guidelines they use for DT. The literature review supports the proposal of a theoretical framework that articulates barriers and challenges to DT in the municipal built asset domain. The application and validation of the framework is then presented, including the detailed methodology, the method of analysis and the results, and the findings and conclusions of the analyses. The implications of the results for research and practice are discussed and the limitations of the study are highlighted. A series of recommendations and future areas of study conclude the paper.

2. Systematic review of the literature and methodology
2.1 Existing framework
DT is a widely studied and published topic. Indeed, approaches and strategies to digitally transform the municipal sector are continuously being introduced, such as e-government, digital city and smart city. From an organizational perspective, past studies have explored DT efforts by governments at all levels (Weerakkody & Dhillon, 2008; Weerakkody, El-Haddadeh, Sabol, Ghoneim, & Dzupka, 2012). These studies have found that process, people, structure, culture and information systems are the typical components of organizational DT within government (Nograšek & Vintar, 2014; Pedersen, 2018). However, many studies have focused on only one or two components and have tended to neglect the relationships between them, while historically, these components have been addressed in a systemic fashion in other domains (Bostrom & Heinen, 1977; Nograšek & Vintar, 2014; Al-Emadi & Anouze, 2018). While the various components which frame DT have been identified, a generalized lack of empirical evidence on the strategies and approaches enabling DT in a systemic and

structured way is lacking (Coursey & Norris, 2008). In particular, urban infrastructure AM lacks a framework for DT.

However, past literature has explored and characterized barriers and issues to DT in-depth (Tangi, Janssen, Benedetti, Noci, & August, 2020). Table 1 presents and summarizes the categories of each of the nine existing frameworks, adapted to their contexts and locations of study.

Looking at different frameworks including those presented in Table 1, several similarities and differences emerge. Most frameworks focus on the organizational challenges and change management associated with DT in the public sector. Specific contexts influence the components of each framework. Although some aspects such as governance, organizational culture and processes are addressed in a similar way, the specific categories studied and the perspectives adopted may vary from one framework to another. Some frameworks focus more on the technical aspects of DT, while others emphasize the political, cultural or organizational aspects.

By analyzing the recommendations and conclusions of each framework, it is possible to identify good practices and lessons learned. However, it should be noted that most of these frameworks are based on specific case studies or limited contexts, which limits their generalizability. There is therefore a need for more research that integrates multiple national and organizational contexts to gain a more comprehensive and in-depth view of DT in the public sector.

While growing attention is placed on municipalities and their DT to support the planning, delivery, use and management of the built assets under their remit as well as the services they deliver, more work is still needed to fully understand and structure this promising and crucial process. Indeed, gaps in knowledge are evident, namely around the absence of research on DT and how it can potentially support UIA lifecycle management activities at the municipal level. The advent of digital twins has introduced new avenues of research which still need to be developed and articulated within the municipal framework. Furthermore, there is little research on DT that takes into consideration the notion of value, especially focusing on improving services and the quality of life for citizens as opposed to monetary value. Within Canada, no research was found that investigates DT of UIA lifecycle management at the municipal level. Lastly, a large portion of research is case study based which limits generalizability of results or is limited to interviews conducted within a single government organization. As such, no research was found that aims to develop and validate a systematic approach to characterize and articulate barriers and challenges to DT within the municipal built asset domain.

2.2 Systematic literature review

To understand the DT needed to support integrated UIA planning, delivery, management and use within municipalities, a longitudinal research project was undertaken which involved a number of municipalities located in the province of Quebec, Canada. A theoretical framework that aims to articulate the barriers and challenges that prevent successful DT to support lifecycle activities relating to UIAs in municipalities was first developed from the literature and validated through workshops. A series of interviews and a survey were then conducted to further extend and validate the framework. Lastly, an in-depth case study of a municipality was conducted over a 9-month period. This paper focuses on the development and validation of the preliminary theoretical framework.

To attain the objectives outlined in the introduction, a systematic literature review was conducted in five steps. Figure 1 summarizes the process used to conduct the systematic literature review. A total of 202 articles were retained following the initial search. Duplicates were removed, resulting in 107 relevant articles. From these, an eligibility test was conducted according to well-defined criteria. A total of 63 relevant articles remained (Table 4), 9 of which served to inform the development of the framework (Table 1).

Area of study	Categories	Context	Reference
Electronic government (*e-government* or *t-government*)	Organizational challenges, process change challenges, cultural and social challenges, and information integration system and technology challenges	British authorities	Weerakkody and Dhillon (2008)
E-government	Governance, organizational and managerial level, and technical level	Three case studies including one city in the Netherlands	Van Veenstra *et al.* (2011)
Smart city	Technology, management and organization, policy context and governance	Philadelphia and Seattle in the United States, Quebec City in Canada and Mexico City in Mexico	Alawadhi *et al.* (2012)
Digital transformation projects in municipalities	Culture, processes, change management, digital skills, demographic and financial challenges	Municipalities in Norway	Ruud (2017)
Digitization of the administration	Internal (strategic, policy and resources) and external	Small and medium-sized towns in a federal system in Germany	Jakob and Krcmar (2018)
Transformational government (t-government)	Context of transformation pressure, public sector requirements, governance complexity, organizational integration, technical integration, organization, structure, organizational culture, processes, people, IT, understanding citizens, capabilities and resources	Public sector organizations in Denmark	Pedersen (2018)
Information and Communication Technology (ICT) in public administrations of public bodies	Structural barriers, cultural barriers, internal and external drivers	Administrations of Dutch public bodies	Tangi *et al.* (2020)
Infrastructure in public organizations	Individual (cultural norms, attitude beliefs and managerial vision), organizational change (human resources and innovation culture) and institutional change (political science and public administration)	23 Swiss sub-states	Manny *et al.* (2021)
Adaptive governance for digital transformation	Organizational barriers; structural barriers, cultural barriers, employee perspective barriers; economic barriers; technological barriers	City in Sweden	Aidanpää and Sjöberg (2021)

Source(s): Table by authors

2.2.1 Identification and collection of articles. Relevant research was identified using two search strategies: a keyword search and a key phrases search. For the keyword search, online search engines such as Google Scholar and Web of Science, Compendex, Inspec, IEEE, Xplore and Eureka.cc databases were used. Some of terms are identified in Table 1. Most of the results of
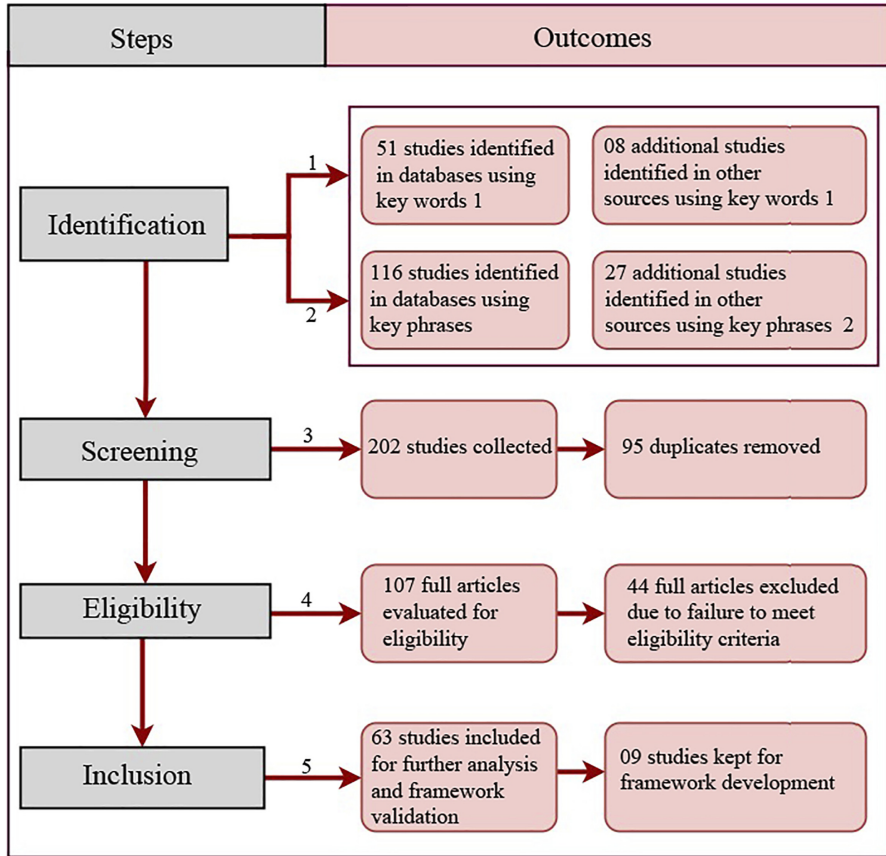
Figure 1.
Refinement steps and
results and number of
related articles

Source(s): Figure by authors

this step were related to the concepts of digital city, e-government and e-administration based on ICT. While the results were deemed relevant, they were not all directly related to DT for municipal UIAs.

The second search built off these initial results to provide a more complete and thorough picture. To assist in the process, specialists from the university library were consulted to better focus the process. In this step, the results from the first step of the research were confirmed and the process was validated. However, expanding the scope of the search failed to produce additional results. At this stage, a series of tools were used to assist with the process, such as developing search equations, searching in multiple languages (English, French, etc.), broadening the search area to include other studies on the same topics and including other search tools, such as Scopus. During this step, additional sources were identified from the reference lists from the reviewed articles. Additional words, phrases, equations and search operators were added during this step (Table 2).

The results of this second step resulted in a broadening of the research scope to include research on topics including smart city, Open Municipal Government (open data), BIM, GIS, City Information Modeling (CIM) and Digital Twin of City.

English	French
Search by keywords	
Barriers	Barrières
Drivers	Moteurs
Challenges	Défis
Barriers	Barrières
Digital transformation of municipalities	Transformation numérique des municipalités
Management of built assets	Gestion des actifs bâtis
Digital twin	Jumeau numérique
Digital twin of cities	Jumeau numérique des villes
BIM	BIM
CIM	CIM
Smart City	Ville intelligente
Search by key phrase	
Drivers digital transformation of municipalities	Moteurs transformation numérique des municipalités
Challenges digital transformation of municipalities	Défis transformation numérique des municipalités
Barriers digital transformation of municipalities	Barrières transformation numérique des municipalités
Barriers of Digital twin of cities	Barrières de jumeau numérique des villes
Barriers to digital transformation of built assets	Barrières de transformation numérique des actifs bâtis
Smart city digital twin challenges	Défis du jumeau numérique de ville intelligente
Smart cities digital transformation	Transformation numérique des villes intelligente
Smart city digital twin barriers	Barrières du jumeau numérique de ville intelligente
Smart city digital twin drivers	Pilotes de jumeaux numériques smart city
Smart City Digital Twins Roadmap	Feuille de route jumeaux numériques smart city
digital transformation of built assets of municipalities Roadmap	Feuille de route transformation numérique des actifs bâtis des municipalités
Sondage pancanadien de transformation numérique municipale	Pan-Canadian municipal digital transformation survey
Sondage de numérisation des actifs bâtis dans les municipalités Canadiennes	Survey of digital transformation of built assets management in Canadian municipalities
Portrait sur la transformation numérique des municipalités canadienne	Portrait of the digital transformation of Canadian municipalities
Search by equations	
(barrier* OR driver* OR challenge*) AND ("digital transformation of municipal*" OR " built assets* management" OR "city* digital twin*" OR "BIM OR "CIM") AND ("smart city" OR "smart cities")	
((barrier* OR driver* OR challenge*) AND (digital transformation of municipal*))	
(barrier* OR driver* OR challenge*) AND ("digital transformation of municipal*" OR "infrastructure assets* management"	
Source(s): Table by the authors	

2.2.2 Screening, eligibility and inclusion. During this step, a more detailed analysis of the 107 filtered articles was done to further validate their eligibility. Information on the source journal, year of publication, topics discussed, among other things, was compiled to facilitate this assessment. The eligibility of the research was determined based on the following set of criteria:

(1) Topic or some content should focus on organizational aspects of public sector DT.

(2) Research from 2002 to 2022 is included.

(3) The search was done in two languages (English and French).

(4) The research selected was peer-reviewed scientific articles, books, and doctoral theses. White papers, non-peer reviewed conference papers, and similar studies by a same author were excluded.

2.2.3 Categorization of barriers and issues to DT found in the literature. Following the identification and screening process, 63 studies were selected and reviewed. Approximately 160 barriers and issues to DT in municipal UIA were identified but given that several were closely related or had similar meanings, these were consolidated and refined. In parallel, the categories of barriers and issues were developed from the past literature highlighted above. They are summarized in Table 3.

06 categories		22 subcategories	
1	Strategy/Governance/steering/leadership/ Financial resources	Lack of guidance and/or leadership	1
		Lack of a strategic plan	2
		Unmanaged external pressure	3
		Lack of governance	4
		Lack of support from senior management	5
		Funding issues	6
2	Process/practice/management	Lack of collaboration	7
		Absence of data management	8
		Misalignment of current practices and management	9
3	Organization/Structure/Culture	Absence of organizational change management	10
		Lack of communication	11
		Lack of training	12
		Non-conducive organizational culture	13
4	Policy/standards/regulations/laws/contracts	Inadequate policy and support from elected officials	14
		Lack or incompatible standards/contracts	15
		Incompatible laws and regulations	16
5	People/Community/Network	Limited vision	17
		Resistance to change	18
		Lack of human resources	19
		Perceptions from the citizens	20
6	Digital/Information Ecosystem	Inadequate technologies and tools	21
		Incompatibility and/or inadequacy of existing information systems	22

Source(s): Table by the authors

Table 3.
Proposed categorizations of DT barriers from the literature

3. Framework design

Past research has investigated drivers and barriers to DT within governmental and/or municipal contexts. As mentioned, these have not focused on municipal built assets and their related services. Thus, a framework has been developed based on a systematic literature review to define a set of elements that can serve to assess the level of integrity of the DT process or initiative and the barriers and issues that can hinder it.

Some 160 barriers and issues were identified and, when relevant, were combined into subcategories. As shown in Table 3, 22 subcategories of barriers divided into six categories have been defined and constitute the proposed theoretical framework.

Table 4 shows the occurrence of barriers identified with the framework within the literature. At a glance, none of the studies identify all 22 barrier subcategories. Alawadhi *et al.* (2012) identified the largest number of barriers, with 14 of the 22 identified. The studies by Aidanpää and Sjöberg (2021) and Van Veenstra *et al.* (2011) identified 13 barriers. The remaining studies identified less than nine.

Categories	Obstacles and challenges	Total
Strategy / Governance / steering / leadership	Lack of guidance and/or leadership	7
	Lack of a strategic plan	4
	External pressure	5
Financial resources	Lack of governance	2
	Lack of support from senior management	2
	Funding issues	6
Process / practice / management	Lack of collaboration	8
	Data management	13
	Current practices and management	13
Organization / Structure / Culture	Structural and organizationel change management	18
	Lack of communication	1
	Lack of training	13
	Organizational culture	10
Policy / standards / regulations / laws / contracts	Policy & support elected off	7
	Standards / contracts	2
	Laws and regulations	5
People / Community / Network	Limited vision	4
	Resistance to change	9
	Lack of human resources	10
	Perceptions of citizens	4
Digital / Information Ecosystem	Technologies and tools	7
	Existing information systems	10
Total:	**22**	**160**

Source(s): Table by the authors

The most frequently mentioned barrier in the review was "lack of organizational change management," which was highlighted in 18 studies. Indeed, the management of organizational change and the reconfiguration of organizational structures are the process of overall or substantial modification of an organization, regardless of its type. The reconfiguration of organizational structures and its business practices and the underlying change management required to achieve it should technically lead to a transformation organization which would have a positive impact, namely on performance. Organizational change is characterized by the pace, willingness and magnitude of change. According to Kurt Lewin (1991), change management goes through three phases: awareness, implementation and adaptation. Moreover, significant organizational change is considered necessary to realize the benefits of DT within organizations (Sun *et al.*; Klievink, Romijn, Cunningham, & de Bruijn, 2017; Surbakti, Pinem, Sembiring, Hamzah, & Nabeshima, 2019). Consequently, the different service lines of an organization must cooperate and integrate their activities by leveraging the possibilities offered by DT in a structured manner, at a pace and within a scope that makes sense for the organization (Layne & Lee, 2001; Dhillon, Weerakkody & Dwivedi, 2008).

Three barriers tied for second place: "absence of data management," "misalignment of current practices and management" and "lack of training"; each was cited in 13 studies. While being identified as a critical aspect of DT by many, effective data management is neglected in the literature (Maciejewski, 2017; Sun, Cegielski, Jia, & Hall, 2016; Surbakti, Wang, Indulska, & Sadiq, 2020). Therefore, the effective use of data requires changes in roles, routines, practices and decision-making within an organization (Klievink, Bharosa, & Tan, 2016; Sun *et al.*, 2016). Also, there are several concerns about security and over-reliance on data for complex problem solving (Giest & Samuels, 2020; Manny, Duygan, Fischer, & Rieckermann, 2021). In addition, data privacy issues lead to distrust (Matheus, Janssen, & Maheshwari, 2020) and poor data management leads to data waste (Mergel, Rethemeyer, & Isett, 2016). In parallel, lack of training also hinders effective DT (Giest, 2017).

The third most mentioned barriers were "non-conducive organizational culture," "lack of human resources" and " incompatibility and/or inadequacy of existing information systems," which were identified in 10 studies. Indeed, the set of attitudes and modes of operation influence behaviors and, consequently, practices in cities. The rational behavior of individuals is influenced by the institutional context and cultural norms of an organization (Scharpf, 2018). Lack of human resources is also one of the most important barriers influencing successful DT (Sun *et al.*, 2016; Ingildsen & Olsson, 2016; Giest, 2017; Manny *et al.*, 2021). However, the availability of IT resources and knowledge does not necessarily imply knowledge in other areas of DT. Lastly, information systems exist to support decision-making and legacy systems are adapted to a context that is no longer suitable. To ensure successful DT, IT departments should work in collaboration with other domains to define a good strategy for data management and use (Klievink *et al.*, 2016).

Building off the notion of change management, "resistance to change" was mentioned in 9 studies. Indeed, reluctance is generally inherent to any change process. Generally, new initiatives and changes are unwelcomed in the public sector for a number of reasons: lack of understanding of the meaning of change, lack of skills (Surbakti *et al.*, 2020), fear of the unknown, lack of trust, personal relationship with old ways of doing things (Alawadhi *et al.*, 2012; Weerakkody, El-Haddadeh, Sivarajah, Omar, & Molnar, 2019) and poor communication (Alawadhi *et al.*, 2012; Walport & Craig, 2014; Tangi *et al.*, 2020). Thus, several behaviors and attitudes indicate an unwillingness to support change or make changes. Employees at the operational level feel that they are neglected when implementing digital technologies (Klievink *et al.*, 2016). Also, many digital initiatives are used to control the

work of employees, which leads to distrust (Alawadhi *et al.*, 2012); the latter is becoming evident in the public sector.

A "lack of collaboration," which was mentioned in 8 studies, and working in silos are identified as barriers. They often stem from existing administrative and institutional structures that define the way of working (Giest, 2017).

A "lack of guidance and/or leadership" and "inadequate policy and support from elected officials" are mentioned in 7 studies. These barriers are significant as DT can potentially affect the whole political cycle (Höchtl, Parycek, & Schöllhammer, 2016), on the input side, from policy processes, (Janssen & Helbig, 2018), to its end, through the implementation of policies through online public services or data-driven policy evaluation (Lavertu, 2016). Established structures and procedures are generally incompatible with today's transformative context. Indeed, public administration actors generally rely on established traditions and "ways of doing things," which can hinder innovation (DiMaggio & Powell, 1983).

While technical advances in digital technologies promise multiple benefits, their implementation in existing organizational structures is often difficult (Wang & Feeney, 2014; Shearmur & Poirier, 2016). Several barriers pertain to the technology and limitations of current operating systems as well as a large number of systems, even though "inadequate technology and tools" are only mentioned in 7 studies. Digital initiatives being implemented are sometimes not tailored to the employees who use them and do not create value for citizens which causes issues in the DT process.

The realization of DT initiatives is often hampered by insufficient financial support. As such, "funding issues" are identified in 6 studies as major barriers. Moreover, in most of the research reviewed, DT is motivated by financial reasons. Some research indicates that city employees interviewed see DT initiatives, such as the smart city, as good for maintaining or even improving the quality of the city. For example, the case study of Värmdö kommun in Sweden shows that as the demographics are changing, the city may not be able to afford to take care of its aging population, as it is not able to increase the number of tax-paying citizens to cover the growing costs, and it has to seek ways to transform its organization (Aidanpää & Sjöberg, 2021). While funding of a DT initiative by the city has allowed for the implementation of digital initiatives, these have been criticized by employees and the media. This criticism is partly because employees and external stakeholders do not realize that financial resources are being allocated to projects to improve the services the municipality offers.

"External pressure" is mentioned in 5 studies. Beyond funding and external perceptions, cities are governed by laws and regulations, which can impede planned changes. Public organizations control resources, procedures and demands. Thus, the organization is limited in what initiatives it can develop and implement. As such "incompatible laws and regulations" appear in 5 studies.

Manager belief and vision are very important for organizational innovation (Rogers, 2003). According to Guenduez, Singler, Tomczak, Schedler, and Oberli (2018), a vision for DT is to provide more well-being with less financial resources. **A "limited vision" for DT and a "lack of a strategic plan" are mentioned in 4 of the studies.** In addition, the appropriate use of large amounts of data is still very limited in the public sector and this is largely due to manager perception toward digitization and data management (Mergel, Kleibrink, & Sörvik, 2018).

Moreover, some public agencies are less inclined to change because of the citizens' concerns. Investments and efforts are being made to improve the performance of cities, according to citizens (Waddock, 2000). However, the trend is to generate more value to justify the funneling of tax dollars toward DT, which implies less spending on initiatives that citizens do support (Knobloch, Gastil, Reitman, & Farnea, 2019).

4. Framework validation

4.1 Methodology and profile of workshop respondents

The second part of the objectives of this first part of the research project focused on validating the framework. As such, a series of workshops were conducted as part of another broader DT project at a multi-governmental level. The data collected were reused and reanalyzed according to the framework developed, given the relevance of the data collected and the approach taken to analyze it. The research team conducted two series of two workshops lasting 90 minutes each independently, in two municipalities. Both municipalities are large cities (population over 500,000) located in Canada. Each workshop was conducted over a two-week period. The objective was to establish a general sense of the two cities' competencies and capacity to support DT and to identify priorities and challenges. Workshop participants were asked to identify barriers to DT, both perceived and real, as part of the workshop. For reasons related to coronavirus disease 2019 (COVID-19), the workshops were conducted remotely by videoconference. During the workshops, participants were separated into subgroups. Participants interacted on an online interactive whiteboard environment using post-it notes.

A total of 16 employees from municipality A participated in workshop A whereas 20 employees from municipality B participated in workshop B. For both cities, the employees were professionals of different departments, ages and years of experience.

4.2 Issues and outcomes from the workshops

During the workshop, participants discussed and answered the following questions:

(1) What do you think DT means for your city?

(2) How do you see this transformation? What are your wishes and needs?

(3) What are its challenges and issues?

Designated participants were identified to share the results of the discussions of the break-out groups in each plenary. Following the workshop, participant responses were consolidated and categorized according to the initial framework (Table 3). Data consolidation is the first important step in sorting and organizing the data so that initial conclusions can be drawn and verified (Miles & Huberman, 2003). This step served as a basis for validating the literature-based framework. Table 5 presents the results of the two workshops whereby researchers discussed and validated the categorization. Both the percentage of responses and total number of responses are indicated. The last row is used to leave comments, namely on the relevance and validity of the subcomponents, e.g., should they be kept, removed or reassigned. As such, "outputs" can be removed from the framework. "Inputs" are subcategories that were frequently mentioned in the workshops and that were not in the original framework, so they could be added.

5. Discussion

An analysis of the workshop data revealed that the greatest concentration of barriers and issues is in "process/practice/management," with 34% and 26% for subcategories "misalignment of current practices and management" and "data management," respectively. Just as in the literature review, "absence of data management" ranked second, while "managing structural and/or organizational change" ranked first.

Compared to the results of the literature review, there are very few or no responses in more than seven subcategories. This may be due to the context of the responses, namely that respondents simply did not think about these issues and/or the responses do not apply to the specific context of these two cases (municipality A and B), without generalizing.

Categories and subcategories	No of responses city A	% of responses city A	% of responses city B	No of responses city B
Strategy/Governance/steering/ leadership/Financial resources	9	7%	6%	8
Lack of guidance and/or leadership	0	0%	1%	1
Lack of a strategic plan	5	4%	2%	2
Unmanaged external pressure	0	0%	0%	0
Lack of governance	0	0%	1%	1
Lack of support from senior management	4	3%	1%	0
Funding issues	0	0%	1%	4
Process/practice/management	47	34%	26%	24
Lack of collaboration	9	7%	6%	6
Absence of data management	18	*13%*	*10%*	9
Misalignment of current practices and management	20	*15%*	*10%*	9
Organization/Structure/Culture	9	7%	13%	12
Absence of organizational change management	1	7%	3%	3
Lack of communication	5	4%	0%	0
Lack of training	2	1%	8%	7
Non-conducive organizational culture	1	1%	2%	2
Policy/standards/regulations/laws/ contracts	6	4%	11%	10
Inadequate policy and support from elected officials	0	0%	2%	2
Lack or incompatible standards/ contracts	6	4%	*9%*	8
Incompatible laws and regulations	0	0%	0%	0
People/Community/Network	20	15%	10%	9
Limited vision	1	1%	1%	1
Resistance to change	11	8%	2%	2
Lack of human resources	8	6%	6%	6
Perceptions from the citizens	0	0%	0%	0
Digital/Information Ecosystem	24	18%	10%	9
Inadequate technologies and tools	10	7%	6%	6
Incompatibility and/or inadequacy of existing information systems	14	*10%*	3%	3
Intrants	22	16%	23%	21
Maturity level/Lack of internal expertise	8	6%	*11%*	10
Asset management/valuable creation	6	4%	8%	7
Process Automation/Digital asset	3	2%	0%	0
Rhythm/long term/life cycle	5	4%	4%	4
Total général	137	100%	100%	93

Source(s): Table by the authors

There are subcategories with a minimal percentage of occurrence, for example, "financing" has a score of 0% (municipality A) and 1% (municipality B). But given that their impact and value are important, neglecting them is a major issue.

Four subcategories emerged, the most cited of which were "AM maturity level" and "digital maturity level". Compared to the results of the literature review, they are considered

"inputs" because the percentage of citations in the workshops is still significant compared to the citations of the other subcategories.

This lack of knowledge about AM and DT and how to link the two areas are two emerging inputs and their importance is paramount. Moreover, they can be considered in the training subcategory. Literature in this domain is relatively new and both inputs are constantly evolving. Therefore, it is not surprising that they were mentioned in the workshop more than in the literature.

Even if the distribution of the two cities' percentages of responses is close, there is still a gap between some of the responses, such as for example, in the area of "existing information systems." Also, for city B, such a low percentage (2%) at the level of "resistance to change" is dubious. These results are understandable, as each city represents a particular context. Each city has its own strengths and weaknesses, and the framework is indeed "agnostic," meaning it is applicable to a wide range of cases.

There is a positive relationship between training, lack of human resources and level of maturity/expertise. The literature also mentioned these as the most important barriers.

The "limited vision" subcategory is moved to the "Strategy/Governance/Pilot" category of the framework. The vision will define where the organization should go, clearly communicate what it wants to achieve as objectives, mobilize and motivate employees to follow this vision, and all this helps to develop the strategy.

6. Conclusion

In response to growing financial, social, and environmental pressures, cities are increasingly turning toward the DT of urban infrastructure AM activities. DT can have a great impact on the organization and its activities and is constantly changing as technology and industry evolve.

This paper presents the results of a first stage of a longitudinal research project aimed at helping cities conduct a planned and structured DT. This DT will lead to the integration of information sources and implementation of digital twins to better meet the needs of citizens and maintain the quality of service over the long term.

As a first step, a systematic literature review was conducted to identify the barriers and challenges in initiating and sustaining a DT. Some directions were also identified to help cities undertake a sustained and structured DT and a picture of the barriers and issues that cities face today and need to reduce and/or eliminate was drawn. A DT framework comprised of 22 areas articulated into six categories was devised. It was validated and refined during two workshops with two large Canadian municipalities.

In the literature review, first 202 scientific studies were identified and examined that discussed the concepts of DT and its impact on cities, its obstacles and challenges, existing DT frameworks and how public organizations adapt to digital development, as well as the guidelines they use for DT. After a refinement process, the number of papers was reduced to 63, in which 9 existing frameworks were presented.

The literature review led to the design of a DT framework that was validated and improved through two workshops in two major Canadian cities. The analysis of the workshop data revealed that the greatest concentration of barriers and issues lies with "misalignment of current practices/management" and "absence of data management." Like the literature review, "absence of data management" ranked as the most important barrier, while "structural and/or organizational change management" ranked first.

Two challenges emerged from the workshops: the level of AM maturity and the level of digital maturity. The lack of knowledge about AM and DT and how to link the two areas is a priority and of paramount importance.

This article contributes to the body of knowledge by shedding new light on the DT at the municipal level. While DT is addressed in the literature from several angles, for example,

e-government, the digital city, the smart city, DT projects in municipalities, digitization of administration, and ICT in public administrations, among others, the present research explores a rarely addressed angle, that of DT for AM at the city level and rarer still, urban infrastructure assets. The expected scientific contribution thus covers part of the gap identified during the literature review.

Moreover, the present research approaches DT of municipal built assets in a systemic way and draws the attention of the practical world to the value that the framework can bring to undertake a pre-planned and federated DT.

7. Limitations and future work

The developed framework offers guidelines that governments can benefit from by anticipating specific barriers and challenges. Limitations include limited experimental conditions, small sample size and a relatively short timeframe. Further work is needed to validate the framework, which is currently underway and presented in part II of the paper. Other approaches are advocated to complement the data collection and analysis to generate more convincing results.

A potential sampling bias could be found with the current study seeing as the sample is limited to two large cities. During data collection, the questions asked of participants are about their perceived impact on their practice. The questionnaire needs to be further developed and written in such a way as to evaluate the framework for validation.

Future research is currently underway to test the generalizability and usability of the findings from the framework and the method used to ensure its validity in real-world conditions, and to adapt it to the context of different types and sizes of municipalities.

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