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Enhancing the Usability and Usefulness of Open Government Data: A Comprehensive Review of the State of Open Government Data Visualization Research

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Abstract

Although open government data (OGD) are becoming widely available, they have not yet reached their full potential due to their limited use. Supplementing OGD with visualizations can make data more engaging, useful, and understandable. We synthesized the academic research on the development and evaluation of OGD visualizations in the *IEEE Explore*, *Science Direct*, and *ACM Digital Library* databases. Our findings suggest four streams of research: 1) description and evaluation of specific examples of OGD visualization, 2) general tools and frameworks, 3) users' needs assessments and evaluation of usability, and 4) other user-related outcomes. While there is a growing robust literature describing specific cases, further empirical research is needed on evaluating the usability of OGD visualizations and tools for different audiences. Promising strategies to enhance the usability and usefulness of OGD are to employ advanced OGD platforms with embedded visualizations and analytics tools and to collaborate with research centers on user studies to ensure that visualizations and analytic tools are useful for stakeholders.

Keywords: Data visualization, citizen engagement, open government data, design strategies, E-government, information literacy, information behavior

1. Introduction

The open government data (OGD) movement in the last decade has encouraged many government organizations worldwide to make their data publicly available to advance transparency and promote the innovative use of data (Attard et al., 2015). However, the current scarce use of OGD has impeded these initiatives from reaching their full potential (Martin, 2014; Ruijer & Martinius, 2017). Studies of the barriers to OGD use have found that data use and understanding require knowledge of data management technologies and statistical techniques. These skills are not available to everyone within a limited time frame (Graves & Hendler, 2014; Janssen et al., 2012), and training programs are needed to improve users' skills and increase their use of OGD (Gascó-Hernández et al., 2018).

Facilitating the dissemination of OGD to common citizens to improve the use of these data remains an open question (Graves & Hendler, 2013). The concern around OGD use by novice users is reflected in a recent European Union project, Raising Open User-friendly Transparency-Enabling Technologies fOr Public Administration (ROUTE-TOPA). Funded as part of a European Commission Horizon 2020, this project aims to improve government transparency by designing and developing technologies that simplify and increase access to OGD and enable non-technology savvy citizens to engage in data-driven debates on societal issues (Osagie et al., 2017). However, beyond this example, governments are in the early stages of moving beyond an initial phase of developing OGD portals and publishing data to an “Open Data 2.0” phase to engage users (Begany & Martin, 2020).

The complexity of OGD platforms and datasets has created a gap between data producers and data users. To bridge this gap, supplementing OGD with visualization can help achieve

broader engagement among different stakeholders (Barcellos et al., 2017; Graves & Hendler, 2014; T. Lee et al., 2020; Pirozzi & Scarano, 2016). Data visualization could help governments meet their OGD objectives by providing a tool to help users make sense of the data and communicate with diverse audiences (Brugger et al., 2016; Graves & Hendler, 2014). To advance the field, we provide a comprehensive review of the OGD visualization literature to describe the state of the field, identify the successes and challenges in current efforts to develop OGD visualizations, identify promising areas for future research, and provide recommendations for practitioners regarding the selection of the appropriate visualization techniques.

1.1 Origins of visualization best practices

Since the first known map in 6200 BC and the first chart of star constellations in 134 BC (Friendly & Denis, 2001), visualization has been appreciated as a means of exploration and communication of knowledge. Traditionally, tabulating and plotting the logical relationships between measured values originates from the need to better understand phenomena such as the spread of disease (Snow, 1855) or economic growth (Playfair, 1821). Recently, a widening range of disciplines is attending to visualization techniques, reinforced by the increased availability of data and accessibility of analytic tools (Friendly, 2006; Liu et al., 2014).

Over this long history, one question has always been of great interest to visualization experts: what are the best strategies for visually displaying information? Tufte's seminal data visualization book described core principles of graphical excellence in displaying quantitative information. He focused on simplicity and proposed that a well-designed presentation of data provides the user with "the greatest number of ideas in the shortest time with the least ink in the smallest space" (Tufte, 1983: p.51). In another seminal work, Cleveland & McGill (1984) built a

theory of graph perception based on their empirical research findings that individuals make more accurate quantitative judgments when comparing two lines rather than two areas or two curvatures. These works and others encouraged future studies to develop principles and guidelines to improve the communication of information in different fields such as epidemiology (Puhan et al., 2006), statistics (Gordon & Finch, 2015), public administration (Isett & Hicks, 2018), and education (Shah & Hoeffner, 2002).

1.2 Recent trends in information visualization research

The recent increased availability of data and analytic tools has expanded the data visualization audience. This expansion has resulted in a stream of information visualization (InfoVis) research concerned with creating the most effective visualizations for data exploration and data communication (Munzner, 2014). InfoVis research focuses on developing new visual displays, designing new tools for specific analytical tasks, and developing perceptual and cognitive theories to understand how humans perceive visual abstractions of statistical data. These recent trends have influenced and inspired visualization research in other fields such as OGD, where visualizations may be a promising way to enhance stakeholders' engagement with and use of OGD.

1.3 Study contributions

Open government data have different types of users, such as entrepreneurs and software developers, journalists, government agency staff, researchers, private industry, and other public users (Begany & Martin, 2020). Data visualization can expand the number, breadth, and engagement of OGD users, and synthesizing the empirical evidence on OGD visualization can help inform future OGD visualization practices. However, such synthesis is challenging due to

the variety of visualization methods, different types of data and users who participated in the studies, and diverse measures used for evaluating user performance and experiences.

To advance the field of OGD visualization, we reviewed the literature to 1) describe the current state of the field; 2) classify and synthesize the existing evidence on the development of OGD visualizations; and 3) summarize the usability, successes, and challenges of these visualization efforts. We found one previous OGD visualization review that identified the most common techniques and challenges (Eberhardt & Silveira, 2018). Our work expands the previous review by 1) examining the usability of OGD visualizations from the user perspective, 2) synthesizing the successes and challenges from the government agency perspective, and 3) offering recommendations for the selection of visualization methods.

We excluded basic information visualization studies in our literature review because they have been extensively reviewed. Examples of data visualization guidelines based on past reviews of the visualization literature include recommendations for choosing the right chart type (Szoka, 1982), recommendations for selecting the necessary elements on each chart type such as confidence intervals for regression lines (Stengel et al., 2008), principles of graphical excellence including simplicity and transparency in showing the data (Gordon & Finch, 2015), and general recommendations on the context, content, and color of charts (Isett & Hicks, 2018). Our unique contribution is a focus on the strategies documented in the OGD literature to enhance our understanding of the existing solutions for improving OGD users' engagement with the content and promising areas of future research in the area of OGD data visualization. We also provide specific recommendations for practitioners regarding appropriate visualizations to include in their OGD platforms.

2. Materials and methods

We used the narrative review method to identify, select, and synthesize articles. A narrative review is a method for reviewing the literature that includes a qualitative summary of the previously published articles and chronological, conceptual, or thematic analysis (Grant & Booth, 2009). The purpose of a narrative review is to bring readers up to date with the current state of the knowledge around a specific topic (Green et al., 2006).

2.1 Search strategy

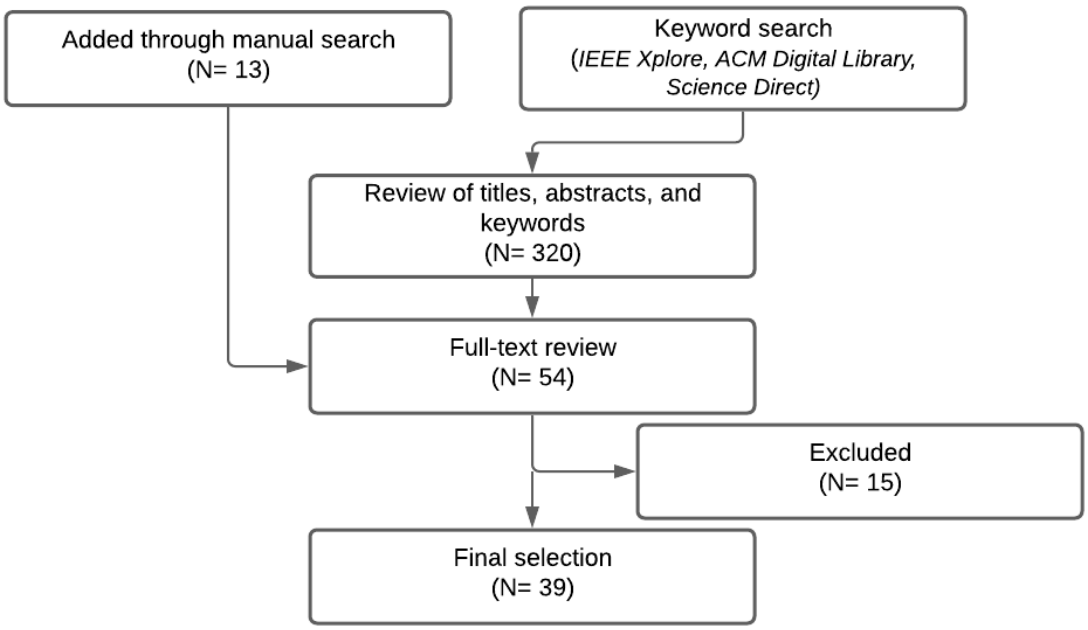
Building on a recent review of OGD literature (Attard et al., 2015), we searched published peer-reviewed articles and conference proceedings (hereafter, articles) for the following keywords: “open government data” OR "government data platform" OR "government data portal" OR "public data portal" OR "public data platform" OR "government data portals" OR "government data platforms" OR "public data portals" OR "public data platforms" in the *IEEE Explore*, *Science Direct*, and *ACM Digital Library* databases. We did not restrict the publication dates. We did not include keywords related to visualization because adding these keywords would limit our search results. This search yielded 320 articles (117 articles from *ACM Digital Library*, 81 articles from *Science Direct*, and 122 articles from *IEEE Explorer*).

2.2 Inclusion criteria for screening the literature

When screening the literature, we sought to include original conceptual and empirical studies that described the development of OGD visualizations, investigated their usability, or examined other user-related outcomes such as user experience. After completing the initial

search, we screened the titles, abstracts, and keywords for instances of visualization, analytics, or usability. At this stage, we excluded duplicates, book chapters, workshops, literature reviews (as they were not primary data analysis), and articles that discussed query systems, virtual or augmented reality, or assistive technology. We excluded OGD articles that did not discuss visualization. The search results were supplemented with a hand search of the references of the included articles and other studies about which we were aware from our past research. Figure 1 summarizes our article selection process that yielded 39 articles for inclusion.

Figure 1. Flowchart of article selection



2.3 Review and synthesis process

The included literature was synthesized to develop a list of research streams regarding the development and evaluation of OGD visualizations. The qualitative synthesis of the studies focused on the description of the tools and their challenges and successes. We reported outcomes if a usability evaluation was conducted. A challenge of the synthesis was that articles were from diverse fields that are interested in different aspects of OGD visualization (such as technical specifications versus user experiences) and have varying norms for reporting methods and results. To address this challenge, three authors with complementary expertise in different aspects of OGD implementation and sustainability, data analytics, data visualization, human-computer interaction, health information, information privacy, and information security jointly reviewed and discussed included articles to extract key elements of each article and synthesize themes. Data extraction was conducted by the first author and the second author verified the extracted data. The third author reviewed a sample of articles. All authors discussed disagreements and uncertainties to achieve consensus about the classification of articles and extracted data. A meta-analysis was not conducted because of the variety of methodologies, such as some articles not reporting any outcomes.

We used a simple classification of study designs for the reviewed articles because they were from diverse disciplines and did not report methods, data, and findings consistently. Furthermore, for many studies, the primary purpose was developing the visualization rather than providing an evaluation which further complicated a clear classification of study designs. We classified study designs into three groups based on whether they included a usability evaluation: 1) no usability evaluation, 2) formal usability evaluation, and 3) informal usability evaluation. We defined formal usability evaluations as studies that described and applied social science

research methods to primary data (e.g., interviews and surveys) or secondary data (e.g., web analytics) to test end users' experiences with the prototype. We defined informal usability evaluations as studies that described the visualization's accomplishments with a narrative explanation of examples of the visualization's use in practice without a formal analysis or clear description of the research methods used to derive insights about usability. Informal usability evaluation might include determinations by the study authors about the visualization's ability to perform desired tasks based on their personal experiences.

3. Results

We found four different research streams in the OGD visualization academic literature: 1) articles providing description and evaluation of specific OGD visualization examples (n=18, summarized in Table 1), 2) articles providing description and evaluation of general architectures and frameworks for OGD visualizations (n=8, summarized in Table 2), 3) articles conducting needs assessments among OGD stakeholders (n=4, summarized in Table 3), and 4) articles evaluating the usability of OGD portals and the effects of portal characteristics on user-related outcomes including acceptance and trust in OGD (n=9, summarized in Table 4). In the following sections, we synthesize the evidence provided by articles in each stream.

3.1 Description and evaluation of specific OGD visualization examples

Table 1 presents the reviewed articles that discussed specific examples of OGD visualizations. These examples came from diverse regions (Albania, Austria, Brazil, Canada, Italy, Mexico, Russia, Romania, South Africa, South Korea, Taiwan, the United Kingdom, and the United States). OGD visualization has been used to improve the accessibility of evidence on

important societal topics such as environmental issues (Lee et al., 2017; Perovich et al., 2021; Radl et al., 2013), public health (Chu & Jiang, 2017; de Mendonça et al., 2015; Park & Gil-Garcia, 2017), and budget and energy resources (González et al., 2014; Knudsen et al., 2018; Sokhn et al., 2016). Furthermore, OGD visualization was used as a complementary intervention to promote behavior change (Van Belle & Hlabano, 2019) and as a tool to involve citizens in policy-making (Gagliardi et al., 2017). Engagement with OGD was further enhanced through the use of storytelling techniques and putting data in context. One of our reviewed studies (Smith, 2013) showed an application of OGD visualization that was enhanced with storytelling techniques (i.e., the visualization was enhanced with animation, images, and stories to make the content relatable) that induced positive discussions on social media. Another study (Perovich et al., 2021) showed an example of "physicalization" (visualizing data with physical objects) that provided participants with a visible, accessible, enjoyable, and memorable experience of OGD. Moreover, linked data and semantic web technologies were used in several OGD visualization examples to facilitate linkages to other local and global data sources, contextualize data, and add extra layers of information (Breitman et al., 2012; Hoxha et al., 2011; Mouromtsev et al., 2013; Spoiala et al., 2016).

The reported challenges of these OGD visualization projects mainly originated from the diversity of data formats, incomplete metadata such as clear data dictionaries, and data formats that required many preprocessing steps (Breitman et al., 2012; Hoxha et al., 2011; de Mendonça et al., 2014). The diverse methods to store data in HTML pages and security measures that prevented automatic extraction were additional barriers to efficiently extracting data from other government webpages (Mouromtsev et al., 2013; Spoiala et al., 2016). A reported challenge of enhancing visualizations with storytelling features is that existing organizational structures may

restrict the formation of the multi-disciplinary content creation teams that are needed to execute data storytelling (Smith, 2013).

Some articles provided useful approaches to deal with these challenges. For example, Park & Gil-Garcia (2017) suggested that using university-based research centers can serve as knowledge brokers to help government agencies understand the usability issues of their data reporting systems and reduce the technical and organizational barriers that government agencies face in enriching and visualizing data for OGD stakeholders. Smith (2013) suggested that making arrangements with media agencies that specialize in "data journalism" prior to releasing OGD visualizations allows for greater reach to the public. Finally, Perovich et al. (2021) recommended partnering with community organizations and using a participatory action research methodology to improve researchers' understandings of community needs, align data displays with ongoing advocacy efforts, and facilitate community ownership of data.

3.2 General tools and frameworks for OGD visualization

Table 2 summarizes the articles that introduced general tools and frameworks for facilitating and enhancing OGD visualizations. Three articles discussed visualization tools that can help non-technical users by automatically extracting metadata (e.g., types of variables) and recommending appropriate visualizations (De Donato et al., 2017; Graves & Bustos-Jiménez, 2015; Pirozzi & Scarano, 2016). Two articles suggested tools that exploit linked open data technology to create visualization frameworks that can enhance OGD analysis by linking related datasets and providing recommendations for other datasets of potential interest to users (Burkhardt et al., 2014; Mijović et al., 2016; Sinif & Bounabat, 2019). Two articles described tools that facilitated user engagement in data-driven policy debates to promote evidence-based

policy-making. For example, as part of the ROUTE-TOPA project, Cordasco et al. (2017) developed the Social Platform for Open Data (SPOD) that provided a virtual space to engage citizens and local organizations in data-driven discussions and knowledge creation through user-friendly visualization tools, OGD co-creation tools, and a blog to showcase results. In another project, Kukimoto (2014) built an interactive display system with a touchscreen interface and a smartphone controller that could be operated by multiple users simultaneously to enhance evidence-based debates.

Regarding the evaluation of the proposed tools, two articles did not report any evaluation (Pirrozi & Scarano, 2016; Burkhardt et al., 2014), three articles reported informal evaluations (De Donato et al., 2017; Mijovic et al., 2016; Sinif & Bounabat 2019), and three articles reported formal evaluations (Graves & Bustos-Jiménez, 2015; Cordascoa et al., 2017; Kukimoto, 2014). Evaluations were conducted at different stages of the design. Graves & Jimenez (2015) stated that the production of their prototype was done through a co-creation method whereby users provided formative feedback in the early stages of the development process, which was used to improve the tool. In the other three studies, a summative evaluation was conducted in the final stages of design (De Donato et al., 2017; Cordascoa et al., 2017; Kukimoto, 2014). The results of these evaluations provided preliminary evidence that the suggested tools can support their targeted audiences.

3.3 Stakeholder needs assessment of OGD visualization

Table 3 shows the reviewed articles that assessed stakeholders' needs related to OGD visualizations. Topics studied included classifying OGD stakeholders, exploring the needs of different stakeholder groups, and understanding the working environment that might boost OGD

practices. Graves and Hendler (2013) created five user profiles of people interested in OGD: government data providers, government data consumers, researchers/journalists, civil programmers, and common citizens. The authors argued that OGD visualization tools are most beneficial for government data providers, government data consumers, researchers, and journalists. Civil programmers and common citizens may be less interested in visualization tools because programmers already possess data visualization skills, and common citizens are likely most interested in consuming the visualizations rather than creating or reusing them. While Graves and Hendler (2013) intended to provide a comprehensive classification of all groups of OGD stakeholders, other studies focused on specific groups. For example, Brugger et al. (2016) focused on three political intermediary groups (political parties, non-governmental organizations, and journalists), which they defined as the bridge between data producers (i.e., government) and data consumers (i.e., civil society). The authors found that among the three intermediary groups, only journalists were actively engaged with OGD visualization; however, their attention was limited because of the initial time investment to learn about the available data and analysis tools. Khayyat & Bannister (2017) characterized the process of co-creation of OGD services and products by various stakeholders, including data providers, communities, businesses, academics, and other experts. Choi & Tausczik (2017) characterized the work experience of civic hackers and data journalists who were involved in projects to create OGD analysis tools (e.g., a tool to browse political contributions in the state of Illinois, USA) or to prepare OGD analysis reports (e.g., an analysis of the time required for people to get out of minimum wage jobs). The authors found that these projects were mainly exploratory; as such, simple descriptive statistics and data visualizations were heavily used for data exploration and communicating results.

Characterizing different user-profiles and work experiences yielded some insights into stakeholders' needs and requirements. For example, Graves and Hendler (2013) developed a set of requirements for OGD visualization that entail: 1) providing a preliminary visualization after a few interactions from the user; 2) implementing mechanisms for users to understand the data and metadata behind a visualization; 3) facilitating communication between government data providers and users such as consumers, researchers, and journalists to enable them to ask and answer clarifying questions; 4) simplifying access to Facebook, Twitter, or other platforms to share visualizations; and 5) recording and encoding the visualization process to allow for the deconstruction, modification, and creation of new versions of a visualization. Some of Graves and Hendler's (2013) findings, such as providing a visualization after a few interactions and implementing a mechanism to help users understand the data and metadata, were confirmed by Brugger et al. (2016). Upon observing participants' exploratory use of OGD datasets, Brugger et al. (2016) learned about practical obstacles to wider use of OGD visualization. These included incomplete contextual information in data descriptions that would allow users to understand the data and lower their time requirements for data cleaning or manipulating visualization tools. Choi et al. (2017) found that teams conducting OGD analysis projects were smaller, had a lower turnover, and used mostly synchronous collaboration; these findings suggested a low usage of universal and technologically-mediated platforms in OGD projects. Finally, Khayyat & Bannister (2017) found some requirements for enabling co-creation in OGD, including raising awareness, bringing in fresh thinking, supporting communities, providing and applying standards, consulting with global experts, inspiring with examples and showing outputs, maintaining good communications, understanding and addressing barriers, and harnessing teamwork.

3.4. Evaluation of usability and other user related outcomes regarding OGD portals

Table 4 shows the reviewed articles that assessed the usability and other user-related outcomes regarding OGD portals. Usability can be generally defined as the extent to which an information product is easy to use and provides a positive user experience. There is some evidence that strengthening visualization tools on OGD portals can enhance their usability. One of our reviewed articles proposed a benchmarking usability framework to systematically evaluate OGD portals (Máchová et al., 2018) on 14 criteria within three categories: 1) open data specification (7 criteria: description of datasets, publisher of datasets, thematic categorization and tags, up-to-date release, machine-readable format, open data license, and visualization and statistics), 2) open data feedback (4 criteria: documentation and tutorial, forum and contact form, user rating and comments, and social media and sharing), and 3) open data requests (3 criteria: request form, list of requests, and involvement in the process). Máchová et al. (2018) used this framework to evaluate the usability of national OGD portals in 5 countries (Australia, Canada, India, the United Kingdom, and the United States), and found two main weaknesses: first, visualization and analytics tools were immature or missing; and second, the evaluated OGD portals did not provide enough support to actively engage stakeholders (for example, contact forms and discussion forums were mostly missing and commenting was only allowed on some portals). This usability framework was used in another study (Nikiforova & McBride, 2021) to evaluate OGD portals in 41 countries, which yielded similar problems with the existing portals including a lack of data request features and visualization/analytics tools.

One usability enhancement tool for OGD portals is the Transparency Enhancing Toolset (TET), which is the data analytics and visualization component of the ROUTE-TOPA project to enhance the user-friendliness of OGD portals. This toolset provides a completely new user interface for OGD portals. It starts with a Google-style text box to search within the repository,

provides an improved presentation of results, including a dataset view with appropriate filtering, and offers guidance on creating visualizations of selected datasets (ROUTE-TO-PA Working Group, 2020). One article (Osagie et al., 2017) evaluated how this toolset improved the usability of OGD portals on several dimensions: 1) search functions (relevance, accuracy, and clarity), 2) data resource views (simplicity, understandability, and structure), 3) data descriptions (understandability and informativeness), and 4) social discussions on data resources (relevance, informativeness, and understandability). Participants enjoyed the simple Google-style user interface to search for datasets and the filters to narrow their search results. Participants also reported that the on-screen guiding process helped them easily create data visualizations.

Beyond usability, the reviewed articles provided evidence that visualization tools can enhance other outcomes related to users' performance and experience with OGD portals. In terms of users' performance, a sensemaking evaluation study (Barcellos et al., 2017) showed that participants generally performed better in noticing outliers, making inferences, and generating hypotheses about the data when offered visualizations rather than raw OGD tables, although working with some unfamiliar types of visualizations (particularly multivariate visualizations) was challenging. In terms of perceived usefulness, an online survey experiment comparing infographic and textual information published on South Korean government websites (Lee et al., 2020) showed that infographics caused less information overload, which was associated with higher perceived website usefulness. A usability evaluation of OGD portals in the Philippines and subsequent interviews with data analysts and laypersons (Chua et al., 2020) showed that although there were differences in users' data display preferences, with laypersons preferring a mixture of numbers and text and data analysts preferring raw datasets and tabulated data, all participants suggested that visuals and infographics are good alternatives for data presentations.

Regarding acceptance and trust, a survey of 200 OGD users with different nationalities (Purwanto et al., 2020) found that users' perceptions of OGD system quality, which can be enhanced by features such as usable data documentation, availability, responsiveness, and data visualization tools, influenced users' perceptions of data quality and their trust in OGD.

Despite the positive evidence for the value of usability enhancement tools, there is variation in their adoption. One article used web analysis to evaluate 20 OGD portals in Australia (Chatfield & Reddick, 2017) in terms of open data provision, data format variety, open data policy intensity, and entrepreneurial data services (e.g., analytics tools, hackathon competitions, and data modeling capabilities such as geospatial mapping or API services). Regarding the provision of entrepreneurial data services, 9 out of the 20 portals provided data analytics tools to promote active citizen engagement, and the availability of these tools was associated with jurisdictions' population size and the intensity of their open data policies (e.g., governments that focused on civic engagement and open service innovation were more likely to provide data visualization tools on their portals). Finally, a survey of 111 OGD users (Zuiderwijk et al., 2016) found that acceptability and use of OGD technologies (e.g., linked open data vocabularies, visualization and analytics tools, and APIs) were impacted by the technology performance expectancy, effort expectancy, social influence, facilitating conditions, and voluntariness of use.

4. Discussion

Open government data initiatives aim to increase the availability of free and easily discoverable government data for use by diverse stakeholders and to enhance government accountability. However, the benefits of opening data will only be realized if the data are used and understood uniformly among all individuals (Park, & Gil-Garcia, 2017). Supplementing

OGD with visualizations has the potential to improve the quality of public information sharing, thereby achieving a broader audience and increased use.

To advance the knowledge and use of OGD visualizations, we conducted a comprehensive literature review of the state of the field. In the past decade, numerous OGD visualization studies have examined four themes: 1) descriptions and evaluations of specific OGD visualization examples, 2) descriptions and evaluations of general architectures and frameworks for OGD visualization, 3) needs assessments of OGD visualization stakeholders, 4) evaluations of usability and other user-related outcomes. These studies have taken place in diverse international settings and contributing authors are from diverse disciplines. Most articles focused on descriptions of specific examples and a smaller number of articles provided general architectures and frameworks that could be used in future practices. The reviewed studies offered some lessons on the successes and challenges of OGD visualization for other governments interested in integrating visualizations. There are some limitations and knowledge gaps that suggest areas for future research. We elaborate on these points below.

A major finding from our synthesis of the specific examples in the literature is that OGD visualizations have been used for diverse purposes, in numerous geographic regions worldwide, and by federal and local governments. This suggests that visualization tools have great potential for enhancing OGD practices in different domains such as public health, transportation, education, and others. The general tools that we reviewed provide feasible solutions to achieve different goals such as creating automatic visualizations for non-technical users (Graves & Jimenez, 2015; Pirrozi & Scarano, 2016; De Donato et al., 2017), exploiting linked data technology to provide context to datasets (Burkhardt et al., 2014; Sinif & Bounabat, 2019; Mijovic et al., 2016), and enhancing data-driven debates among citizens (Cordascoa et al., 2017;

Kukimoto, 2014). Based on early experiences developing the general tools, it is likely that they can be adapted to improve the impact of OGD.

Successes and challenges of OGD visualization were documented in two streams of research: 1) studies on usability and user-related outcomes and 2) specific OGD visualization examples. Usability studies illustrated how visualization and analytics tools could enhance the usability of and user experience with OGD portals. However, as suggested by our reviewed articles (Zuiderwijk et al., 2015; Chatfield & Reddick, 2017), there was individual and organizational variation in the adoption of these tools. At the individual level, the acceptability and use of OGD visualization tools could be enhanced by social influence and incorporating these technologies into individuals' work routines (Zuiderwijk et al., 2015). At the organizational level, the adoption of these technologies could be enhanced with more intense open data policies that focus on civic engagement and open service innovation (Chatfield & Reddick, 2017). Our review of specific examples found that data quality (e.g., diversity of data formats, undocumented data dictionaries, and incompleteness of the data) was a common challenge for creating OGD visualizations. Furthermore, we found that while multi-disciplinary content creation teams were needed to create and enhance OGD visualizations, existing organizational structures may inhibit such teamwork (Smith, 2013). Two recommendations from the reviewed articles to resolve these challenges when creating and distributing OGD visualizations are to involve community organizations in the design process (Perovich et al., 2021) and to use university research centers as knowledge brokers to help government agencies enrich and visualize their data for OGD stakeholders (Park & Gil-Garcia, 2017).

Our review highlighted the successes and challenges of implementing OGD visualizations, but at a more basic level, OGD publishers must first choose the right visualization

technique. The optimal technique depends on the specific tasks that users seek to accomplish, but some general visualization guidelines can help designers improve their OGD visualizations. A recent synthesis of visualization guidelines (Munzner, 2014) provided several tips based on the information visualization literature. First, three-dimensional visualizations should be avoided unless users' tasks involve examining the shape of an inherently three-dimensional structure, such as medical imaging. Second, if simple one-dimensional structures such as lists can represent the data, more complex structures such as node-link networks should be avoided because they require more space to show the same data. Third, to the extent possible, it is desirable to offer multiple views on a single screen because it is easier for users to switch their eyes between different views than to compare the current view with a prior view that is stored in their memories. Fourth, an effective presentation of information includes the following sequence: an overview that displays the entire dataset, zooms and filters that allow users to focus their selected data on regions of interest or other dimensions, and providing details on demand to allow users to conduct in-depth investigations. Fifth, selection of colors should allow for accessibility by persons with color vision deficiency. Finally, although functionality, novelty, and beauty of visualizations are all important, functionality should be prioritized because some novel and beautiful forms may be hard to interpret.

In addition to the above visualization guidelines, several strategies might increase users' engagement with data visualizations. First, embellishing charts with visual metaphors such as people, cars, animals, and flowers can improve users' engagement and the memorability of visualizations (Bateman et al., 2010; Borgo et al., 2012; Borkin et al., 2013; Haroz et al., 2015). Second, animated visualizations can engage users with data that communicate transitions or changes over time (Amini et al., 2018; Heer & Robertson, 2007; Robertson et al., 2008). Third,

data storytelling and interactive designs can improve users' engagement and comprehension of data (Bach et al., 2016; Badam et al., 2016; Chan & Qu, 2016; Kim et al., 2018). However, this literature is evolving and some of these strategies are debated. For example, interactive designs may require more time and attention from users (Munzner, 2014), and visual metaphors and animations may adversely affect users' comprehension of charts when there are many data points (Archambault et al., 2011; Borgo et al., 2012; Haroz et al., 2015; Robertson et al., 2008). Future studies on these topics could be beneficial for enhancing OGD visualization.

In reviewing the literature, we identified several common study limitations and knowledge gaps that would be promising areas for future research. The most critical gap is that while there were numerous case studies describing specific visualization tools, they were not always evaluated with user studies. Among the articles that included a usability evaluation, less than half (3 out of 8 studies) employed a formal usability evaluation with a clearly-described social scientific research method, data collection, and data analysis. The remaining studies used informal evaluations such as study authors' personal experiences with the visualization. There are several ways to conduct usability evaluations such as asking experts' opinions on the extent to which websites conforms to usability principles, collecting primary interview and survey data about users' experiences with prototypes, examining secondary data such as site engagement metrics in web analytics data, and conducting laboratory experiments to assess how users perform with the website. Another promising area for future research is to create standard frameworks to assess the usability of OGD visualizations. One of our reviewed articles (Brugger et al., 2016) created an assessment tool based on a literature review and interviews with Swiss political intermediaries but did not apply it to the study's subsequent visualization exercise using Swiss OGD datasets due to the authors' interview-based findings that political intermediaries

have limited experience with OGD. We found a benchmarking framework that could be used in usability evaluations of OGD portals, but it only assessed the existence of OGD visualization tools and not their quality (Máchová et al., 2018). A fruitful area for future research would be developing standardized measures of usability for OGD visualizations that can be applied broadly across settings to develop more generalizable insights.

Another knowledge gap is examining the role that visualization can play in mitigating the privacy and security concerns regarding the publication and use of OGD. Privacy concerns are essential to general OGD practices to the extent that they are mentioned in the original OGD principles (Attard et al., 2015). Janssen et al. (2012) included "non-privacy-restricted and non-confidential data" in their OGD definition to emphasize its importance. However, there is a trade-off between preserving personal data privacy and enhancing the utility of published data. Visualization tools can play an important role in mitigating security and privacy concerns both as a privacy-aware and security-aware communication channel and as an analytic tool for understanding privacy parameters and data sharing policies (Bhattacharjee et al., 2020). There is a gap in the OGD visualization literature on the analytics tools that can be used to examine and mitigate privacy and security concerns while simultaneously providing public access to usable data.

There are several limitations to our literature review. First, although we attempted to conduct a comprehensive search of the computing and digital government literature, we potentially missed OGD visualization studies in specific domains such as public health and geographic information systems that are published in domain-specific databases outside the scope of our search (i.e., IEEE Xplore, ACM Digital Library, and Science Direct). Second, our literature review encountered two major methodological challenges that we mitigated through

our search and data extraction procedures. In some studies, visualization was only part of the broader effort to increase the usability of OGD portals. To ensure our review would be comprehensive, we did not include "visualization" in our keyword search. Instead, we relied on OGD-related search terms following the approach by Attard et al., 2015, supplemented by a manual search for "visualization" in the title, abstract, or author-indexed keywords. This approach helped us to expand our findings to capture more studies that discussed OGD visualizations. The second major challenge was to extract and report information from the reviewed articles consistently. The reviewed articles were from multiple fields that have different norms for reporting methodologies and results. For example, studies from the computer science field were primarily focused on describing the tool being developed whereas studies from the digital government field included longer theoretical sections. Conference proceedings and journals had different styles and norms for reporting study details such as the number of participants and data collection method. We took several measures to improve the reliability of our data extraction and ensure a correct interpretation of studies: 1) we established a three-member team with complementary methodological, theoretical, and disciplinary expertise relevant to the articles, 2) we had frequent discussions within our team regarding the study design elements of each article, 3) we used an iterative approach to develop refined categories to describe the different study designs after reviewing all articles, and 4) we had multiple reviewers examine each article with discussions to resolve disagreements in the data extraction. Third, because of the variety of methodologies and research approaches, we were unable to conduct a systematic quality assessment or a meta-analysis and instead focused on a qualitative presentation of key findings and common study limitations.

5. Conclusions

Based on our synthesis of the reviewed articles, we have a few recommendations for future researchers interested in OGD visualization. Overall, the quality of evidence in our reviewed studies could be improved. Many of the studies described use cases and prototypes without systematically evaluating their usefulness for OGD audiences. Even when there were formal usability assessments, the research methods were frequently not clearly described in a way that could be reproduced or adapted to other settings. Specific recommendations for conceptualizing future studies are: 1) using the evidence from qualitative studies and needs assessments to inform future tools, 2) including usability evaluations into different development stages when creating general architectures and specific OGD visualizations, 3) enhancing usability evaluations by testing visualizations with diverse OGD stakeholders, and 4) exploring the usefulness of new visualization practices such as data storytelling and privacy-preserving visualizations.

Our literature review has some implications for policy and practice. First, government agencies could enhance their OGD visualizations by collaborating with academic research centers to conduct user studies and integrating the development of OGD visualizations into routine work practices rather than as special projects. Second, government agencies could implement more comprehensive open data policies that go beyond simply posting OGD online to focusing on civic engagement and employing advanced OGD platforms with embedded usable visualizations and analytics tools. Third, OGD publishers could strive to improve the quality of OGD by providing more complete data in structured data formats along with data dictionaries, given our findings that the quality of published datasets was a common challenge in producing usable OGD visualizations. Finally, publishers should improve the quality of OGD visualizations using strategies such as storytelling to engage users with the data and collaborating with

community organizations to learn about specific problems of interest to citizens and how to involve the organizations in creating and enhancing OGD visualizations. Employing these practices can enhance the usefulness of publicly shared data for different stakeholders.

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