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Living, Breathing Data: Sharing and Interpreting Green Infrastructure Data to Promote Behavioral Change

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LIVING, BREATHING DATA: SHARING AND INTERPRETING GREEN INFRASTRUCTURE DATA TO PROMOTE BEHAVIORAL CHANGE

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Abstract

Green infrastructure is a sustainable and climate resilient approach to urbanization that reduces the impact that we as humans have on our environment. Traditional impermeable infrastructure causes excessive stormwater runoff, which disrupts the nutrient balance and water properties of the surrounding watershed. Green infrastructure installments such as porous pavement, rain barrels, and green roofs provide various ecosystem services, and restore urban water quality. As communities shift to being more climate resilient, the responsibility to develop green infrastructure rests on individuals as well as institutions. The Rochester Museum & Science Center in Rochester, New York, has constructed a Green Infrastructure Showcase on their campus and is working with the Rochester Institute of Technology Environmental Science Program to collect data and assess the efficacy of their green infrastructure. The goal of this thesis is to communicate that data to the public by using Tableau, an online data visualization platform, and by prototyping an interactive software demo that could be installed within the museum. This thesis addresses the following research question: How can scientific data visualizations and dashboards be used to convey meaningful conclusions about green infrastructure to the public? This question is explored by examining engaging exhibition components and visualization design and by analyzing four case studies. The intended outcome of this project is threefold: to share data from the green infrastructure showcase; to visualize and interpret scientific data for visitors to the museum; and to show how data may promote behavioral change. The thesis offers a method for museums to share numerical data in a way that is more engaging than a static display of numbers. This thesis proposes that living, breathing data—quantitative information presented as a series of data visualizations that visitors can interact with—fosters visitor engagement and may motivate visitors to change their behavior in

order to be responsible stewards of the environment. Ultimately, by creating data visualizations, interpreting the data, and sharing it with the museum’s public, museums have the capacity to encourage individuals and communities to make more informed decisions about how to implement green infrastructure in their cities and in their daily lives.

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Introduction

Data that is collected from scientific research is often only shared with other researchers and academics. Bringing complex data as relevant content to display in a museum setting may help visitors understand the relationship between the different variables present in the data, and use this information to make conclusions that are applicable in their daily lives. This concept is applicable to the data that is being collected at the Rochester Museum & Science Center, which has constructed a green infrastructure showcase on their campus. This showcase includes a green roof, rain barrels, porous and permeable pavement, bioretention areas, pollinator habitats, and a meteorological station. The goal of this showcase is to show how beneficial green infrastructure is for all of us, and to help the community implement green infrastructure in their homes, businesses, and schools. The Museum & Science Center is working with students from RIT's environmental science program to collect data on the efficacy of their green infrastructure, which provides insight into the longevity of the green infrastructure installations and examines the quality and quantity of stormwater runoff. This project-based thesis seeks to interpret and present this data to the public. Ideally, this would be done digitally using online dashboards and a prototype interactive software, as well as physical interpretive materials to provide context to museum visitors. To provide the appropriate research foundation for this project, the literature review below explores the topics of engagement in exhibition design and data visualization for public consumption. Included at the end of the literature review are the case studies that inspired this thesis.

Literature Review

Essential Exhibition Features for Engagement

There is extensive existing research on the specific factors of an exhibition that will result in the most engagement from visitors. Two researchers, Toni Dancu and Lisa Sindorf from the Exploratorium Museum in San Francisco conducted a study examining Exhibition Design for Girls Engagement (EDGE).[1] The EDGE project visited over 300 exhibitions at three American science museums, and studied almost 1,000 youth aged 8-13, as they interacted with those exhibits. Dancu and Sindorf identified nine attributes that were the most important for girls' engagement, none of which negatively impacted engagement from boys.[2] Further writing by these researchers defines four synergetic strategies constituting a female-responsive design framework,[3] outlined in Table 1.

Table 1: Strategies for a female-responsive design framework. Table designed by author.

• Create a low-pressure setting	• Provide meaningful connections
• Enable social interaction and collaboration	• Represent females and their interests

[1] Toni Dancu and Lisa Sindorf, "Exhibit Designs for Girls' Engagement (EDGE)," *Curator: The Museum Journal* 61 (July 1, 2018), https://doi.org/10.1111/cura.12267.

[2] The nine EDGE design attributes identified are as follows: a) Exhibit labels should use a drawing; b) exhibit labels should include an image of a person; c) exhibits should include a familiar object; d) exhibits should encourage a playful or humorous atmosphere; e) exhibit labels should feel homemade and personal; f) the exhibit should have multiple stations; g) the stations should have space to accommodate three or more people; h) interactions should be open-ended; and i) visitors should be able to watch others to preview the exhibit before engaging with it. Note that the order in which these attributes are listed does not signify their importance.

[3] Toni Dancstep (née Dancu) and Lisa Sindorf, "Creating a Female-Responsive Design Framework for STEM Exhibits," *Curator: The Museum Journal* 61, no. 3 (July 2018): 469–84, https://doi.org/10.1111/cura.12268.

This framework is similar to what has been found by Neta Shaby *et al* in their research studying a total of 1800 students interacting with 9 exhibitions.[4] The goal of this study was to understand the extent to which students were willing to engage with the interactives, and then identify the features of those exhibitions that were responsible for the most engagement. The findings from this research indicated that visitors were more likely to be engaged in familiar topics, and reinforced previous findings that exhibitions are the most engaging when they accommodate for groups of visitors and facilitate social interaction.

It is especially important when creating digital exhibitions to consider how they will facilitate groups of visitors. This is analyzed in detail by researchers Christian Heath and Dirk vom Lehn from King's College London in their 2008 journal article *Configuring 'Interactivity': Enhancing Engagement in Science Centres and Museums*.[5] Heath and Lehn examine multiple different science center exhibitions and discuss the linear, constrained sequences of actions present in their "interactives" which impairs collaboration between multiple visitors. They concur with previous research that social interaction stimulates informal learning and contend that interactivity in and of itself does not naturally give rise to social interaction, or vice versa. Often the hardware with which digital exhibitions are implemented—be it the size of the monitor or the user interface design, or another component of the exhibition— fails to accommodate for more than one user at a time.

These concepts will be included as part of this thesis project design, which relies upon visitors, including children, interacting with digital data visualizations at the museum. The most important takeaway from the aforementioned paragraphs is that interactive exhibitions are most

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[4] Neta Shaby, Orit Ben-Zvi Assaraf, and Tali Tal, "The Particular Aspects of Science Museum Exhibits That Encourage Students' Engagement," *Journal of Science Education and Technology* 26, no. 3 (2017): 253–68

[5] Christian Heath and Dirk vom Lehn, "Configuring 'Interactivity': Enhancing Engagement in Science Centres and Museums," *Social Studies of Science* 38, no. 1 (2008): 63–91.

engaging when they accommodate for social interaction, are relevant to a familiar subject matter, and propagate an open-ended, low-pressure environment in which the exhibition can be freely explored. It will likely be very challenging to apply these concepts to exploratory digital data visualizations, especially when accommodating a group of people is dependent on a certain level of hardware fidelity to display any visualization software.

Fundamentals of Data Visualization

A necessary step to visualizing data in a museum setting is to determine what kind of visualizations you can effectively use to convey information to museum visitors. Mary Ann Wojton, a researcher and project manager at the Center of Science and Industry (COSI), based in Columbus, Ohio, has developed a constructionist model for interpreting data visualizations.[6] Her research introduces the Simple-Familiarity Matrix, which is specifically applicable to presenting complex data visualizations as part of an exhibition. In the model, the effectiveness of data visualizations conveying information to museum visitors is evaluated via the familiarity of the subject matter and the simplicity of the visualization itself. These two axes create 4 possible visualizations: simple and familiar, complex and familiar, simple and unfamiliar, and complex and unfamiliar. A visualization is considered “simple” if it involves dichotomous data, akin to what might be learned in elementary school. As more variables and dimensions are included, the visualizations become more complex. Topics that are less familiar to visitors would necessitate a simpler visualization, such as a bar graph or pie charts, while familiar topics would merit a visualization that is more elaborate. All visualizations should be accompanied by supportive contextualization and interpretation. Even after creating a simple-familiarity matrix, it can be

[6] Mary Ann Wojton et al., “Begin at the Beginning: A Constructionist Model for Interpreting Data Visualizations,” *Curator: The Museum Journal* 61, no. 4 (2018): 559–74, https://doi.org/10.1111/cura.12277.

difficult to decide what type of chart to choose for specific applications. To assist in the chart selection process, novice designers may refer to one of the many available online chart selector tools. These chart pickers allow designers to quickly determine what type of visualization to design “at a glance” with unfamiliar datasets. This has been explored by researchers Chen and Zheng at the National Taipei University of Technology, who have found that these chart chooser tools allow designers to express their creativity and draw more charts than those who do not use a chart chooser.[7] This can be especially useful when chart designers are unfamiliar with the subject matter, or when time is of the essence.

Beyond these two examples which address the broad decision-making process that goes into choosing a type of visualization, the subtle rules of designing informational graphics are discussed at length by Judith A. Moldenhauer, Professor of Art in Graphic Design at Wayne State University. She explains the methods by which charts can be concise, with clearly defined visual elements that draw attention to certain features, cautions against adding extra visual baggage, or “chart junk.” The end goal of a scientific visualization is to communicate the relationship between the different variables present in the data, and this needs to be reflected in the visual elements of a chart for that visualization to be effective.[8] This concept is further emphasized by Jefferson Bailey of the Metropolitan New York Library Council and Lily Pregill of the New York Art Resources Consortium in their journal article “Speak to the Eyes: The History and Practice of Information Visualization,” which examines visualizations from as early

[7] Ching-I Chen and Meng-Cong Zheng, “Online Interactive Chart Choosers for Novice Visual Designers: Assistance and Restriction,” in *Design, User Experience, and Usability. Interaction Design*, ed. Aaron Marcus and Elizabeth Rosenzweig, Lecture Notes in Computer Science (Cham: Springer International Publishing, 2020), 83–96, https://doi.org/10.1007/978-3-030-49713-2_6.

[8] Judith A. Moldenhauer, “Visualizing Information in Scientific Figures,” in *Design, User Experience, and Usability. Interaction Design*, ed. Aaron Marcus and Elizabeth Rosenzweig, Lecture Notes in Computer Science (Cham: Springer International Publishing, 2020), 426–38, https://doi.org/10.1007/978-3-030-49713-2_29.

as the start of the 19th century, and as late as 2013, using these examples to contextualize infographics as we know them today.[9] Building upon this historical background and drawing connections to today's interdisciplinary practices, including uses in digital humanities and information sciences, Bailey and Pregill discuss how visualizations come to be in the museum setting, often being created by digital humanists, software developers, or enthusiastic supporters. They conclude that the existence of modern complex infographics is dependent on public accessibility of collection data and a willingness on part of the museum to collaborate with data-inclined researchers. Data visualization itself is empowering, being potentially informative, explicit, argumentative, clarifying, or by fitting a variety of other functions. The article by Bailey and Pregill is very relevant to the work that is being done as part of this thesis, which revolves around bringing collected data into the museum and sharing it with the public using visualizations.

Building upon the essential engagement features in exhibitions and the methods and history of data visualization, the following sections of this literature review addresses case studies from science museums that provide exemplars of data visualization and, in some cases, interactivity.

Case Studies

1. *Plankton populations*

[9] Jefferson Bailey and Lily Pregill, "Speak to the Eyes: The History and Practice of Information Visualization," *Art Documentation: Journal of the Art Libraries Society of North America* 33, no. 2 (2014): 168–91, https://doi.org/10.1086/678525.

Plankton Populations is an interactive digital visualization tool that can be found on exhibition at the Exploratorium in San Francisco.[10] The exhibition receives 850,000 visitors a year, and it is relevant to this thesis because it is an interactive visualization of a scientific dataset created specifically to be used in a museum. Joyce Ma, who worked on the exhibition, explained the entire design process and the lessons that were learned in her research article "Living Liquid: Design and Evaluation of an Exploratory Visualization Tool for Museum Visitors.[11]" The exhibit was created in collaboration with University of California to engage visitors with emerging research on oceanic microbes using an interactive software installed on a 55-inch multi-touch tabletop (Fig. 1).[12]

***Figure 1**: Users interacting with the Plankton Populations exhibit at the Exploratorium.*

The development prototype of this exhibit was called *Living Liquid*, and it was designed through three rounds of formative evaluations, each of which resulted in an important

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[10] Joyce Ma, Kwan-Liu Ma, and Jennifer Frazier, "Decoding a Complex Visualization in a Science Museum – An Empirical Study," *IEEE Transactions on Visualization and Computer Graphics* 26, no. 1 (January 2020): 472–81, https://doi.org/10.1109/TVCG.2019.2934401.

[11] Joyce Ma et al., "Living Liquid: Design and Evaluation of an Exploratory Visualization Tool for Museum Visitors," accessed September 7, 2021, https://ieeexplore-ieee-org.ezproxy.rit.edu/document/6327286.

[12] Image Courtesy of Ma et al, "Decoding a Complex Data Visualization in a Science Museum," p. 2

visualization design decision. First, designers decided what data to visualize to initiate inquiry. Second, they needed to decide how they could link microscopic organism data to global trends, and finally, they considered how to include data that would allow users to pursue their own questions. The exhibition was renamed to *Plankton Populations* after the prototype stage.

2. Museum Makers and OH-Kids

Research for this thesis also explored how data can be used to facilitate learning outside of the museum setting. Data-driven workshop activities hosted by museum professionals facilitate STEM learning in children. This was carried out by professional museum educators and researchers at the New York Hall of Science (NYSCI), who developed an after-school program with the primary goal of introducing families with young children to data science in an informal setting.[13] This program creates a positive initial experience with data science and STEM subjects for children much earlier than they would begin learning about it in school. Furthermore, museums can support STEM programs in a formal setting by developing experiential learning about STEM topics that can be conducted while students are at school. One such program, OH-Kids, is described by Adrián Pedrozo-Acuna, an associate professor at Universidad Nacional Autónoma de México who specializes in flood risk management and coastal engineering.[14] This program installed real-time precipitation monitors on the rooftops of primary and secondary schools in Mexico City, and then developed educational activities that were engaging and relevant to the everyday lives of students. As depicted in Fig. 2[15], the children begin with a

[13] Susan M. Letourneau et al., "Museum Makers: Family Explorations of Data Science through Making and Exhibit Design," *Curator: The Museum Journal* 63, no. 1 (2020): 131–45, https://doi.org/10.1111/cura.12348.

[14] Adrián Pedrozo-Acuña et al., "An Innovative STEM Outreach Model (OH-Kids) to Foster the next Generation of Geoscientists, Engineers, and Technologists," *Geoscience Communication* 2, no. 2 (2019): 187–99, http://dx.doi.org.ezproxy.rit.edu/10.5194/gc-2-187-2019.

[15] Image courtesy of Predrozo-Acuña et al, page 190.

questionnaire, followed by a short introductory lecture, and then they move into 15-minute games and physical models, and finish with another questionnaire that assess what the children have learned.

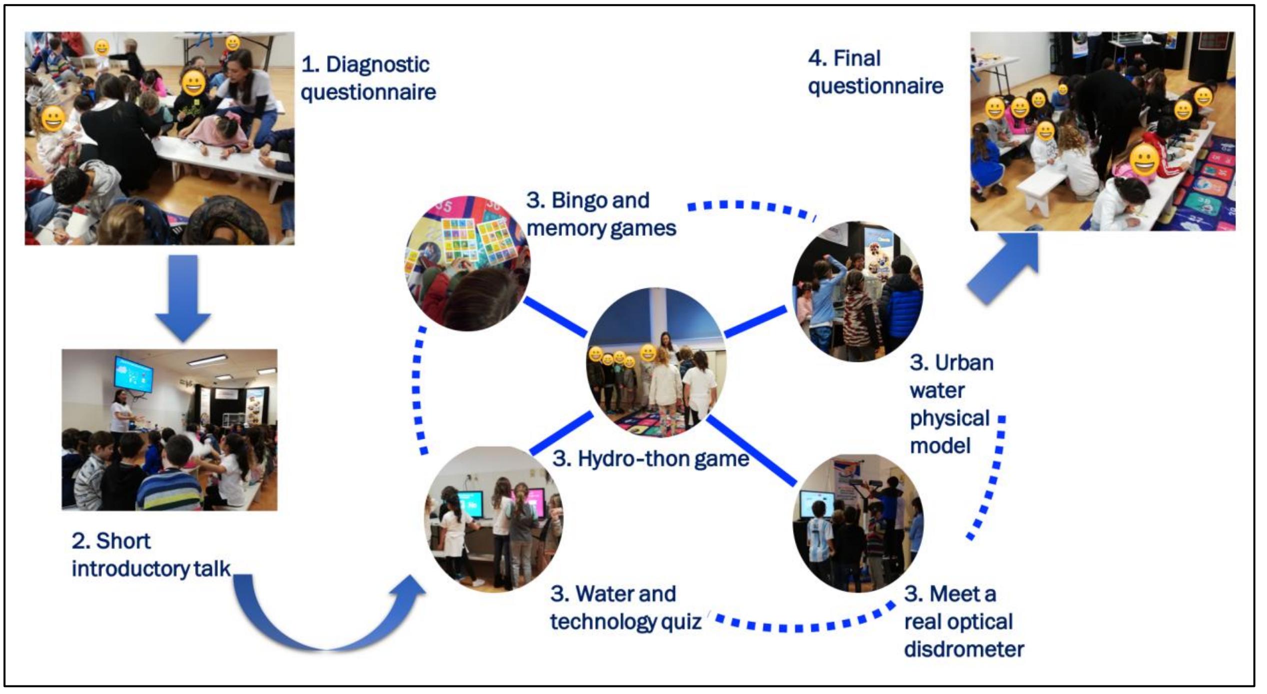

***Figure 2**: Order of activities performed during OH-Kids workshop.*

The results of the final questionnaire indicated that the urban water physical model and meet a real optical disdrometer activities significantly impacted how students perceive science and the water cycle, while the other three activities reinforced retention of key concepts. This case study is particularly noteworthy because the RMSC Strasenburgh Planetarium also has a meteorological station on the roof that is collecting various atmospheric weather data, including precipitation. Furthermore, they will soon be installing four more automated temperature loggers around campus which could also be implemented in a workshop such as OH-Kids.

3. Murry-Darling Outreach Project

The third case study addresses data and community voice and public influence on environmental issues, which are key facets of this thesis and green infrastructure in general. Community voice in environmental issues was explored as part of a 2002 collaboration between the National Museum of Australia and the Murray-Darling Basin Commission, a natural resource management agency. Together they launched the Murray-Darling Outreach Project (MDOP). An article in the Australian Journal of Public Administration explores how the MDOP builds community voice and civic engagement.[16] The MDOP includes two youth programs designed to encourage youth engagement in civic activities, as well as two community partnerships. One of the goals of these community partnerships was to capture the interests of those members of the community who were not already involved in environmental issues. Evaluation of these community programs found developing a sense of "Place" that linked cultural heritage to the natural environment was an effective method to draw participation from those who would feel alienated by scientific discussion of environmental issues.

4. *Tableau in a Museum Setting*

This project utilizes Tableau, an existing online data visualization platform used to make exploratory dashboards, which may be used by a museum to make internal decisions in addition to being visible by the public. Jessica Mailhot, a Museum and Field Studies graduate student at University of Colorado-Boulder (CU-Boulder), has used Tableau to visualize collections as part of her graduate thesis work. Mailhot created 5 dashboards, their respective tutorials for future use by museum staff, a proof-of-concept trial, and a website. The desired outcome of this work was

[16] Ruth Lane et al., "Museum Outreach Programs to Promote Community Engagement in Local Environmental Issues," *Australian Journal of Public Administration* 66 (March 20, 2007): 159–74, https://doi.org/10.1111/j.1467-8500.2007.00525.x.

for data visualizations to become more accessible for Natural History Collections (NHCs).[17] Mailhot addressed four barriers faced by NHCs: (1) Most museums typically do not have the time or spare funding to explore data visualization, and so only a small portion of NHCs are able to experiment with creating dashboards; (2) Use and customization of existing museum dashboards requires coding knowledge, which is not common among or expected of NHC staff; (3) Training for data visualization software exists but is not targeted towards NHC staff; (4) Existing NHC dashboards were designed in isolation and require a significant learning curve to use each one.

Contextual information about the project

Urbanization, Stormwater Runoff, and why Green Infrastructure is needed

Urbanization is the process by which human cities expand and grow. It is expected that 67% of the global population will live in urban settings by 2050, with a total of 6.7 billion urban residents[18]. Infrastructure in urban areas is generally more susceptible to deterioration due to a higher rate of use than infrastructure in rural areas.[19] Furthermore, the American Society of Civil Engineers found that the investment needed for water infrastructure in the United States has outpaced available funding, with capital spending on water infrastructure meeting only 37% of the needed investment in 2019. Combined sewer systems are particularly in need of replacement

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[17] Jessica Mailhot, "Visualizing the Future of Collections: How to Make Data Visualization Accessible and Useful for Managing Collections and Museums:," *Collections*, March 22, 2021, https://doi.org/10.1177/1550190621998325.

[18] United Nations, Department of Economic and Social Affairs, and Population Division, *World Urbanization Prospects: The 2018 Revision*, 2019.

[19] "Failure to Act: Closing the Infrastructure Investment Gap for America's Economic Future" (Reston,VA: American Society of Civil Engineers, 2016), https://infrastructurereportcard.org/wp-content/uploads/2016/10/ASCE-Failure-to-Act-2016-FINAL.pdf.

or retrofit due to the frequency with which they overflow and discharge untreated water to local water bodies.[20] This problem will likely be made worse by the intensifying rainfall that is expected to occur in the northeastern U.S. as a result of climate change[21].

Green infrastructure is any man-made construction that provides ecosystem services, such as managing stormwater flow or providing habitat for plants and pollinators. Examples of green infrastructure include green roofs, permeable pavement, bioretention areas and rain barrels. Cities have begun work to replace and retrofit existing infrastructure with hopes of decreasing both combined sewer overflow events and the overall volume of runoff into the sewer system and ecosystems.

The RMSC Green Infrastructure Grant Program

The Rochester Museum & Science Center (RMSC) is located in central Rochester, a historically industrial town that is home to influential corporations such as Eastman Kodak Company, Xerox, and Bausch & Lomb. RMSC is home to over 1.2 million collection objects, four floors of gallery space, and 200 hands-on exhibitions that receive over 385,000 annual visitors.[22] The mission of RMSC is to inspire a better future for all through curiosity, exploration, and participation in science, culture, and the natural world. The Regional Green Infrastructure Showcase at the RMSC was developed as part of the New York State Environmental Protection Fund's Green Infrastructure Grant Program (GIGP). In its first phase, bioretention areas, the green roof, porous asphalt, rain barrels, and interactive exhibits were installed; the second phase

[20] "Failure to Act: Closing the Infrastructure Investment Gap for America's Economic Future."

[21] K. Noake et al., "Changes in Seasonal Land Precipitation during the Latter Twentieth-Century," *Geophysical Research Letters* 39, no. 3 (2012), https://doi.org/10.1029/2011GL050405.

[22] RMSC, "RMSC MASTER Fact Sheet," March 30, 2021, https://rmsc.org/files/RMSC_MASTER_Fact_Sheet_-_Updated_3.30.21.docx.pdf.

included additional porous pavement surrounding the stormwater tree pits. The Environmental Science Program at Rochester Institute of Technology has been working in collaboration with the RMSC to analyze the long-term efficacy and durability of the Green Infrastructure Showcase. We are currently in the sixth year of this 10-year project. We are evaluating the impact of green infrastructure on water quality and quantity, quantifying the temporal and spatial change in porous pavement infiltration rates, assessing auxiliary ecosystem services provided by green infrastructure, and assisting the RMSC with the operation of their new meteorological station.

Methodology

Datasets

All the data that is included in this thesis was collected on RMSC campus by RIT Environmental Science Capstone students as part of their Green Infrastructure Grant Program (GIGP) project.[23] This collaboration started in 2015 with the primary goal of assessing the longevity and capability of the green infrastructure found on RMSC campus. There is a lot of data available that has been collected by GIGP capstone teams over the years, but the three main datasets that I will be focusing on are: 1. The porous pavement infiltration rate, and 2. The green roof plant and soil assessment and 3. The atmospheric weather data collected by the meteorological station on the roof of the Planetarium.[24] The porous pavement and green roof datasets are relatively small and have been collected for multiple years. One of the major

[23] This thesis, combining the museum's green initiatives and preparing interpretive material for the public, are a result of my dual interests in environmental science and museum studies. As a double major seeking a BS degree in two colleges (College of Science and College of Liberal Arts), in 2021-22 I served on the Environmental Science team, and captured data from the museum while also developing this paper and visualizations for my museum studies major.

[24] Rochester Museum & Science Center and RIT Environmental Science Program, *Green Infrastructure Data Sets*, 2015-2022, Unpublished.

challenges involved in working with this data is that a new group of students is collecting the data each year, and the methods of collection tend to vary from year to year. The meteorological station has been collecting atmospheric weather data every minute since December of 2018 that the station was being powered. The data that was included in this thesis was averaged weekly to create smoother visualizations.

Porous Pavement Infiltration Rate

This data is collected to assess how porous pavement prevents stormwater runoff and to determine how the stormwater infiltration rate is affected by wear and tear and general degradation over time. The dataset consists of the linear infiltration rate and volumetric flow rate of 36 different sites within the RMSC front parking lot. This data might interest visitors because it explains some of the benefits of green infrastructure. Most notably, porous pavement prevents water from running off into nearby sewer systems or the natural water table by allowing water to infiltrate downward into the soil. This prevents accumulated pollution on the parking lot from being discharged directly into the sewer system or nearby streams. Furthermore, water theoretically does not get trapped in this pavement during wintertime, preventing expanding ice from creating potholes. More intense periods of rainfall are going to be more common in the future, so a viable porous pavement that requires less maintenance and is less expensive in the long run may be very beneficial to home and business owners. The methodology for collecting this data is included under Appendix Table 1. Infiltration data was collected in 2019, 2020, and 2021, however the methodology for collection has changed slightly to accommodate for changing field conditions, which has resulted in a significantly different scale of results each year. This variation makes it very difficult to determine precise changes in infiltration rate, but there is enough information to say that the infiltration rate of the porous parking lot has decreased over the past three years.

Green Roof Plant & Soil Assessment

Starting in 2020, GIGP teams have been recording the amount of each plant species present on the green roof at the RMSC. The green roof plant assessment data was collected by using a lift to climb onto the roof, dividing the green roof into four quadrants, and counting (or approximating) the quantity of plants of each species in each quadrant. This data has been collected in 2020 and in 2021. Soil samples were also collected in 2019 and 2021, from which the moisture, organic matter and carbon content of the green roof soil has been determined.

We can make several interesting conclusions from this information, despite it being a relatively small dataset. We know how biodiverse the green roof is. We know that only 3 out of the 20 plants found on the roof last fall were planted there intentionally. The plants found on the green roof have been classified as either flowering plants, grasses, weeds, or trees, which is pertinent info to anyone who is considering building one of their own. In addition to absorbing stormwater, the plants on a green roof can also provide habitat for pollinators, as well as sequester a small amount of carbon. Furthermore, green roofs are significantly cooler than traditional roofs, and can contribute to mitigating urban heat island effects.[25] Something to keep in mind when constructing green roofs is that they are heavy, especially after being saturated with water after a large storm.

[25] OAR US EPA, "Using Green Roofs to Reduce Heat Islands," Overviews and Factsheets, June 17, 2014, https://www.epa.gov/heatislands/using-green-roofs-reduce-heat-islands.

The Meteorological Station Datalogger

In 2018, the RMSC installed a meteorological station on the roof of the Strasenburgh Planetarium that automatically collected data on various atmospheric weather conditions. Every minute, the attached CR6 Datalogger collects the following data:

Table 2: Data Collected by the Meteorological Station

• Precipitation (inch/hour)	• Wind Speed (miles per hour)
• Temperature (°F)	• Wind Direction (Degrees)
• Relative Humidity (%)	• Barometric Pressure (millibar)

Not all of the data collected above could be included in this thesis, either due to equipment malfunction or a lack of relevance to green infrastructure. As such, the dataset that was used to create Living, Breathing Data from the met station only includes temperature, wind speed, and wind direction. From this information, we can begin to understand how climate patterns are changing at the museum. Further data collection would be very beneficial in this regard.

This thesis includes two different methods of interactive digital data exploration. The first is a Tableau dashboard that is used to explore the green roof plant and soil assessment. The second visualization is a custom-built software demo developed by RIT alumni Christian Martin, which combines several open-source data tools into a single exploratory interactive.[26] This interactive includes the meteorological station data, beginning in 2018, as well as all three years of collected infiltration data.

Guiding principles behind the visualizations

[26] The open-source libraries and interfaces selected by Christian for this project are Bootstrap, Leaflet, Chart.js, Plotly, and d3.

A key element of this thesis is the idea of layering data behind multiple levels of interactivity by the user. Layering enables a wide range of data that can be included in an interactive visualization without being overwhelming to the viewer at first glance. Furthermore, it encourages interactivity by showing the user that there is a reason to explore the visualization to discover new information. This idea is something that is mentioned above in *Plankton Populations* case study, and it has been implemented in both the Tableau dashboards as well as the demo.

The complexity of the visualizations used in this thesis was decided with consideration of the simple-familiarity relationship examined by Wojton et al and discussed earlier in this thesis. It seemed best to make a very simple visualization displaying the infiltration rate of the porous pavement, as this topic is likely unfamiliar to an average person. As such, the infiltration rate data is displayed using only a simple 3-bar chart. The other datasets from the green roof and the met station seem like they would be familiar information to an average person, as one dataset involves analyzing different plant types and the other dataset is comprised of the weather. For this reason, I was willing to include more complex visualizations for these datasets. A chart chooser tool akin to the ones outlined by Chen and Zheng as discussed earlier in this thesis was not used in this project.

Results of the Visualizations

The Green Roof Plant & Soil Assessment Dashboard

This dashboard consists of four different visual elements: A drill down pie chart that displays plant species and their broad categorization as flowers, grasses, weeds, or trees (Fig. 3); an accompanying bar chart that helps to visualize exactly how many of each plant species is present; a dot plot that visualizes the increase in soil organic matter content since 2019; and a small embedded website, https://greenroofs.org, which provides information about the importance of green roofs as well as information to build and maintain your own.

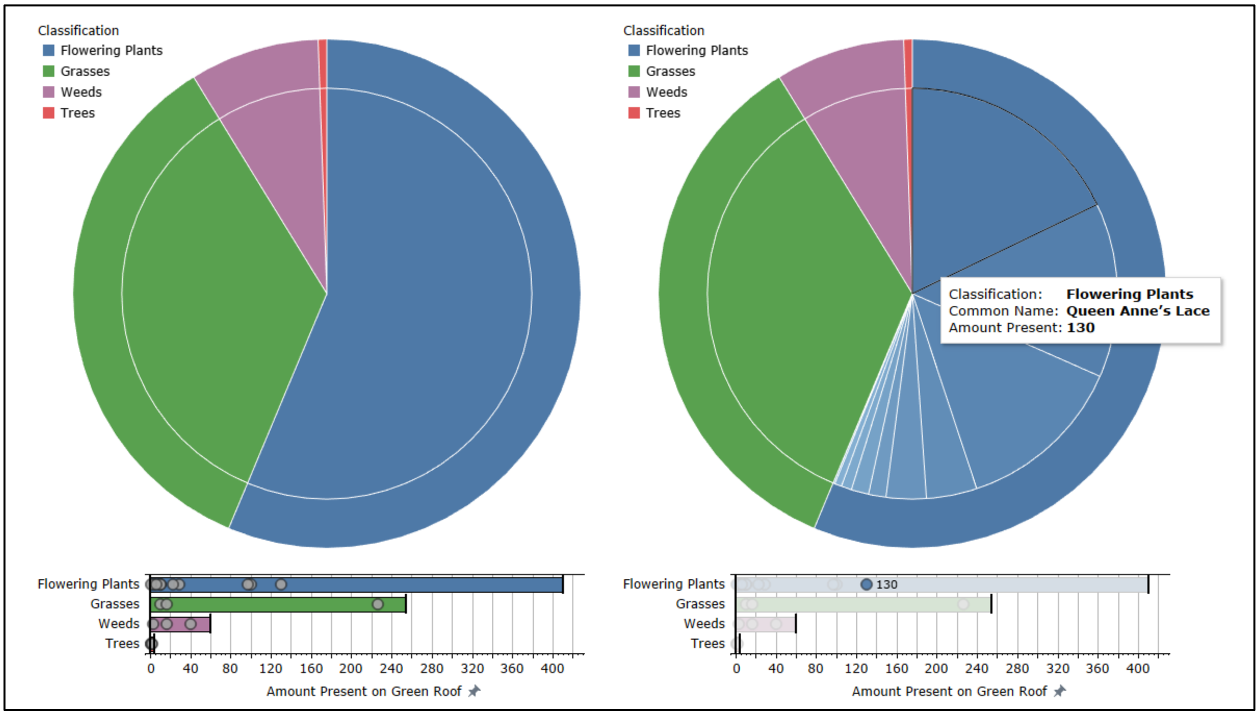


Figure 3*: A pie chart and an accompanying bar chart created for the green roof plant & soil assessment dashboard. Here you can see how the graphic changes upon hover.*

The drill down pie chart at first appears ordinary, but upon hovering over any one category of the pie chart (flowering plants, grasses, weeds or trees), the center part of that categories slice recolors to show the specific species of that category that were found, in a color scale based off of the parent slice. So, as seen in the figure above, after hovering over the flowering plants category and seeing that there were 410 flowering plants present on the green roof, a user can then see that 130 of those plants were Queen Anne's Lace, 100 were White Clover, and so on.

This process is the same for each of the four different plant classifications present in the outer pie chart. The creation of this additional layer of interactivity allows users to explore more specific information at their own discretion. While the tool tip displayed on hover includes the number of species present, there is also a bar chart below the pie chart that helps to visualize exactly how many of each plant category and species are present on the green roof. Hovering over any species or classification on the pie chart highlights that species or classification in the bar chart.

The Interactive Demo

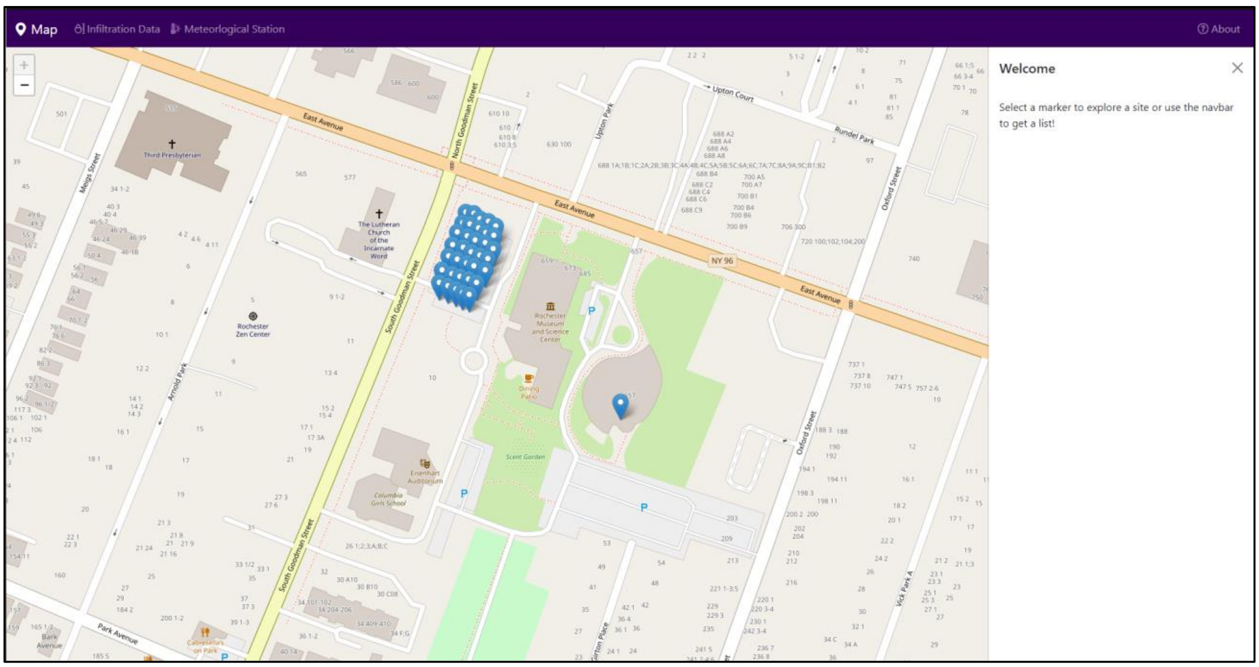


Figure 4*: Landing page and general layout of the interactive demo.*

The UI of the interactive demo consists primarily of a street view map of the RMSC Museum & Science Center campus and surrounding streets, on which data markers can be found that correspond to data that is being visualized. The side panel displays basic instructions to click on a marker to begin exploring data, which is then displayed on the side panel. At the top of the page is a navigation bar that can also be used to navigate through the data, as well as an About page that lists some details about green infrastructure on RMSC campus and the Living, Breathing Data thesis.

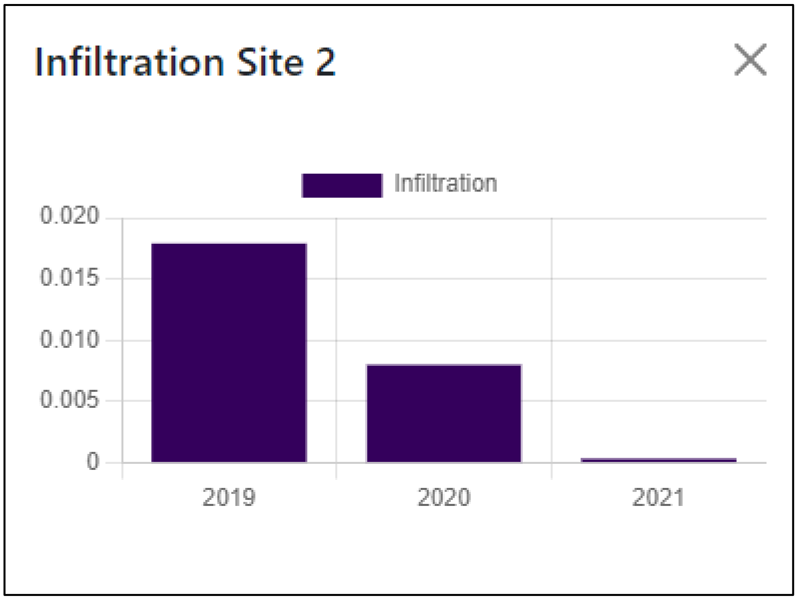


***Figure 5**: Bar chart display of the infiltration rate of various porous parking lot testing sites since 2019.*

Clicking on any infiltration point will display a bar chart of the infiltration rate for that site over the course of three years. Hovering over each bar will show the exact rate. Alternatively, clicking on the Infiltration Data button on the top navigation bar displays a list of all 35 infiltration sites, as well as a short explanation of what this data tells us. Clicking any of the sites out of this list returns the same page as clicking on the site marker on the map.

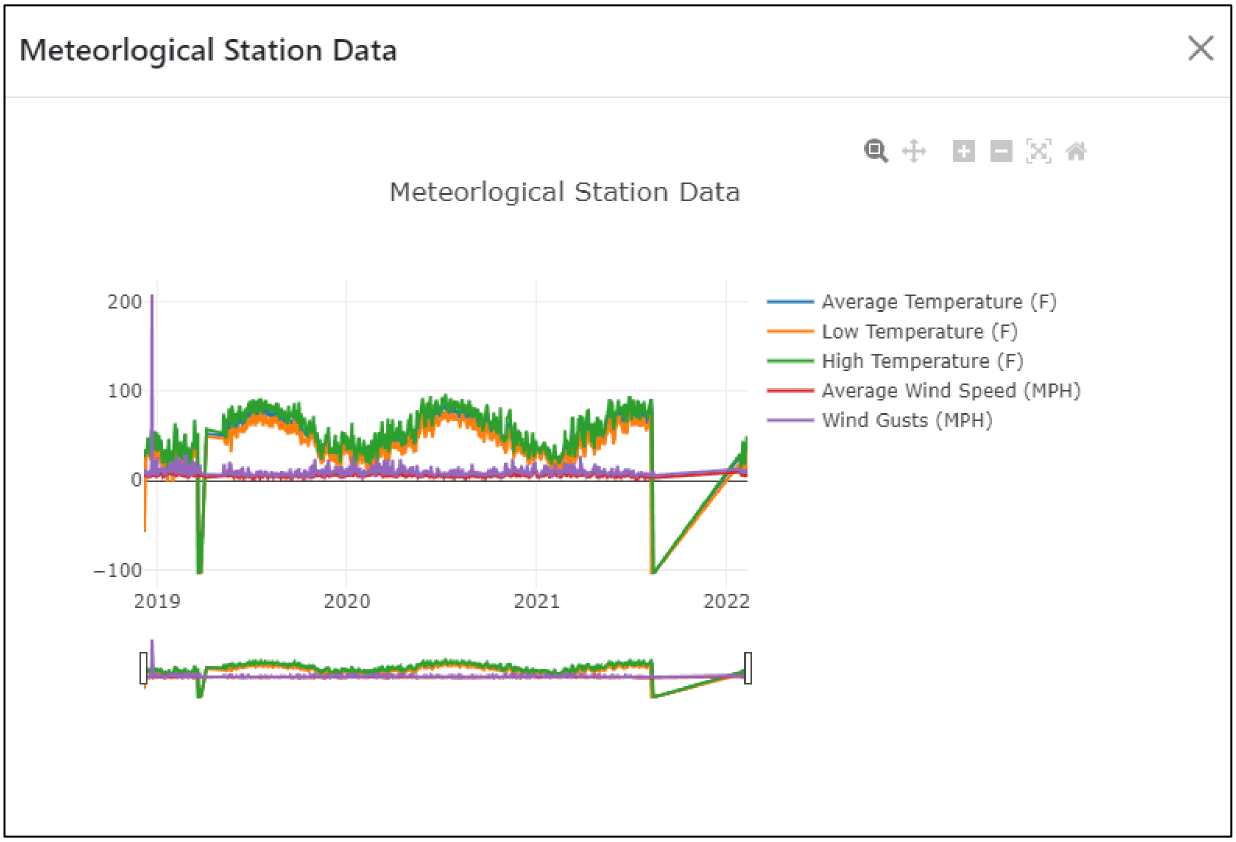


Figure 6*: Pop out window displaying a more detailed visualization of the atmospheric data collected by the meteorological station.*

The meteorological (met) station data exploration works a little bit differently. Clicking the met station marker will show a small line chart on the side panel, with an Explore Data button below the chart. Clicking the Meteorological Station Data button on the top navigation bar also returns this page on the sidebar. Clicking on Explore Data brings up a small window over the map view that has a more detailed line chart that shows the low, high, and average temperatures, wind speeds, and wind gusts. Clicking on any element in the legend will toggle that element on or off. By default, the line chart shows data from December 2018 to January of 2022, but users can zoom in to a specific time scale by clicking and dragging on the chart.

User Evaluation of the Interactive Visualization

Due to time constraints, no user testing was conducted on the Tableau dashboard, beyond review by thesis advisors and the cohort of the museum studies capstone course. However, user testing of the interactive demo took place on RIT campus to gather feedback on how effective the different interactive visualizations were at communicating information.[27] A sample of 24 individuals were presented with the interactive demo and asked to share their opinions about it. Comments were made in real time, and responded to; simultaneously, comments were gathered by a person in the room who served as a scribe and did not offer feedback. Based upon this experience, the feedback may be grouped into two areas: context and interpretation of the data and differentiating the visuals.

In terms of context and purpose, it should be stated that only a basic premise was given before the viewers were walked through the visualization. Immediately, several participants remarked that the demo, on its own, needed a written narrative or introduction to contextualize the visualization for the user. A possible solution to this concern is to add context to the sidebar on the right-hand side of the interactive or perhaps to add a small window with some explanatory text and a start button. Such facets are part of interactive panels commonly found in museums and could easily be incorporated into this presentation of data.

In addition, users struggled to differentiate the data presented. Specifically, they pointed out that the high concentration of data points in a grid on the map of the parking lot was not very intuitive. None of the dots plotted on the grid were numbered, and there was no clear indication of the pin on the map, unless the item was individually clicked. Even if the markers were

[27] The user testing occurred in the MUSE 360: Visitor Engagement & Museum Technologies course on Tuesday, April 19, 2022. Of the 24 participants, 23 were students, of whom 8 were museum studies majors; 15 were not museum studies majors but rather studied disciplines in other colleges, including art and design; computing; engineering; engineering technology; liberal arts; and individualized study. The 24th participant was one of two course instructors, based in the college of art and design.

numbered, they were close together, making it difficult to select specific sites. The lack of differentiation was not tied to aggregation alone: all the data points in the visualization use a small blue pin, including the met station. Thus, no differentiation is apparent, meaning viewers were unsure what type of data corresponds to each point. While this would become a greater challenge with the inclusion of additional datasets, a simple solution is to use different colors for each dataset represented, making color the differentiator of the type of data. Another way to refine the appearance of the data came from one of the users in the testing who suggested eliminating the grid of points and instead creating a small interactive heat map that displays the infiltration rate of the parking lot at various points without having to click on anything.

The key takeaway from this user testing is that without interpretive text explaining what the data means, the visualizations only present the data. Put simply, the visualization presents little more than a simple visualization of the raw data. Without interpretation of what these results actually mean for green infrastructure, the museum, or our community, the dots and points do not function as living, breathing, data, but instead, they are merely pixels on a screen. Without interpretive guidance within the interactive demo, users are only given data, but not the supporting, interpretive information that contextualizes the data, and in turn, brings it into the space of the museum visitor. Therefore, in order to meet the third goal of this thesis, which is to promote behavioral change, the data visualizations would need to include context and challenges to the viewers, as simply presenting the data itself in the visualizations is not enough to connect visitors to the green infrastructure showcase waiting just outside the museum.

Discussion

Limitations of the Visualizations

There are several places where the visualizations could be enhanced to better meet the goals of this thesis and the goal of sharing numerical data in a way that is more engaging than a static display of numbers. However, due to a variety of factors—limitations of the source data; software constraints; and time constraints involved in user testing—the data visualizations offer only a starting point for such an endeavor.[28]

The infiltration data in particular can be very challenging to make definite conclusions from in these visualizations. Because the methodology for collecting infiltration measurements needed to change over time to fit the needs of the GIGP project, each year of results has a very different range of values. Furthermore, at the time of writing this, ten of the 2021 infiltration sites have yet to be measured, which would yield gaps in the visualizations (i.e., a blank section on the corresponding graph in the interactive demo). The infiltration rate of sites that are measured are all substantially lower than previous years as well. Furthermore, much of the data that was collected by the meteorological station was either faulty data, as is the case with the precipitation data, or did not result in a compelling visualization, as is the case with the relative humidity, barometric pressure, and wind direction.

The visualizations as they exist now present what I would call a "limited interactivity," by which I mean that they are interactive and exploratory, but only to a relatively small extent due to the scale of this project, the nature of the visualizations, and the underlying data. There would be far more depth to the interactivity of the visualizations if more datasets were included, or if the included datasets had been collected for a longer period. The visualizations would be very

[28] As noted above, the Tableau dashboard did not undergo any user testing, and as such the potential improvements identified during evaluation of the interactive demo are outside the scope of this project.

difficult for users with impaired vision to explore. I also doubt that children would have very much interest in exploring the visualizations in their current state.

Living, Breathing Data visualizations do not support interaction from multiple users at the same time, which goes against the recommendations of every author cited under the Essential Exhibition Features for Engagement section of this thesis. Interactive data displays need to be designed with social interactivity in mind from the very beginning in order to properly provide an engaging experience. While this thought process was researched and considered as this project was developed, it was ultimately not implemented into the final deliverables. A group of people may approach the visualizations and discuss the experience together, but ultimately only one person at a time can interact with them directly.

Literature Comparison and Recommendations

Of the 9 design attributes that promote engagement identified by Dancu and Sindorf,[29] the only one that is expressed in Living, Breathing Data is the fact that people can preview other users interacting with it. These visualizations could be made to be more open ended if more datasets were included for users to explore but Living, Breathing Data as it exists currently does not provide such an open-ended experience. If the RMSC were to implement a digital data visualization exhibit, then they could fulfill many of the other attributes with the creation of proper exhibit labels, the right atmosphere, and a design that accommodates multiple users at the

[29] Toni Dancu and Lisa Sindorf, "Exhibit Designs for Girls' Engagement (EDGE),"
The nine EDGE design attributes identified are as follows:
A. Exhibit labels should use a drawing, and B. an image of a person.
C. Exhibits should include a familiar object. D. Exhibits should encourage a playful or humorous atmosphere, and E. feel homemade and personal. F. The exhibit should have multiple stations, with G. space to accommodate three or more people. H. Interactions should be open-ended, and I. visitors should be able to watch others to preview the exhibit before engaging with it.
Note that the order in which these attributes are listed does not signify their importance.

same time, akin to what created for *Living Liquid* and *Plankton Populations*[30]. Ma et al. recommended the following design principles for designing public visualizations:

Table 3: Visualization Recommendations by Ma et al.

1. Avoid Distracting visitors from data they should explore	2. Incorporate background information into the visualization
3. Favor Understandability over scientific accuracy	4. Layer Data accessibility to structure inquiry

Living, Breathing Data was created with these principles in mind, particularly 2 and 4 as discussed earlier in this thesis. Following these examples is essential should an interactive digital data visualization be implemented within the RMSC gallery space. Furthermore, it is crucial to create an exhibition that can be used by multiple users at the same time, and that facilitates discussion and interaction between those different users. This could be achieved by creating a single digital interactive component that can be used by a small group of people, akin to what Ma et al. achieved with *Plankton Populations*. Alternatively, multiple interactive stations could be included within the same exhibition, so long as that exhibition guides users into collaborating and exploring the data together. Many of the authors cited in this paper have concluded that facilitating social interaction is a critical component of engaging exhibitions, and I would highly recommend that any interactive visualization that may be created by the RMSC using these datasets is designed with social interaction in mind.

Promoting behavioral change

One of the primary goals of creating interactive data displays about the GIGP is to share the benefits of green infrastructure and to encourage visitors to support the adoption of additional

[30] Ma et al., "Living Liquid."

green infrastructure installations within our community. The RMSC can lead by example here using the green infrastructure showcase that has been installed on the museum's campus. By advancing visitors' understanding of how the green infrastructure on the RMSC campus functions, they may feel more comfortable making decisions about green infrastructure in their own lives. If the museum can implement these things and achieve desired results, what is there to stop local home and business owners from also installing green infrastructure? Another way to connect museum visitors to green infrastructure is to incorporate data exploration workshops similar to OH-Kids or the Murray-Darling Outreach Project, exposing data and the underlying issues of urbanization to the community.

By creating interactive data visualizations of the green infrastructure found on RMSC campus, we are bringing our outside data inside the gallery space. Visitors can then take this information back outside with them, using their understanding of the data visualizations to influence their perception of green infrastructure in their daily lives. The museum must take on the responsibility of defining the impact that green infrastructure has had on their campus using the data that has been collected so far. This data is the mechanism that will translate the impact of green infrastructure at the RMSC into a personal role in the life of a museum visitor.

Recommendations and Future Steps

Having now completed this project, the three recommendations that I would impart to anyone making digital interactive data visualizations in a museum setting are: 1. Visualizations need to be designed to encourage social interaction and collaboration; 2. Interpretive elements play a critical role in assisting users to engage with the exhibition and make conclusions from the underlying data; 3. Visualizations of scientific datasets, particularly those collected as part of an ongoing research project, should be designed to accommodate potential future research, as it may be favorable to update existing visualizations or incorporate new databases into the exhibition at a later date.

The inclusion of more datasets would be very beneficial to this project. There are several other types of data that are recorded and collected as part of the GIGP project being carried out by the environmental science department at RIT, such as stormwater nutrient and conductivity analysis, stormwater quantity data and analysis as collected by several different automated data recording devices, and as of this year, ecosystem services data and assessment. The inclusion of these datasets would allow for visualizations that are more informative, more interactive, and would better show the interconnected relationship of different elements of green infrastructure. Such inclusions would do a lot more to present a realistic understanding of the capabilities of green infrastructure and why its implementation at home or in the local community would be beneficial.

It is also important to consider how the existing visualizations could be updated in the future as more data is being collected. The GIGP is an ongoing project, and new data is collected every year, so this is something that the RMSC would need to be conscious of if they ever decide to officially share data with the public using any of the means outlined in this thesis. For the Tableau dashboards, while the source data sheets could be updated to include more data, it would be difficult to include this information on the dashboard without remaking the graphics from the ground up. The interactive demo on the other hand can add new data very easily by updating the spreadsheets that the visualizations are based on. Adding a new year of data collection to the spreadsheets will automatically create a new entry for that year in the corresponding charts. However, adding entirely new datasets that are not already present in the demo would be much more challenging than a simple edit, and would require coding a new visualization.

One of the biggest considerations that people have when deciding to install green infrastructure is cost. While there is existing research about the long-term expenses of green infrastructure compared to traditional impervious infrastructure, this information is not communicated as part of this thesis, as these visualizations only include data that is collected as part of the GIGP project, which has very little to do with the economics of these installments. Including such information as a companion to or as part of these visualizations would be very beneficial to homeowners that are considering the implementation of green infrastructure in their home lives. There is a wealth of existing literature discussing behavioral science and what influences our consideration of new ideas and will to make a change in our lives, the study of which may be beneficial to promoting behavioral change as a result of this data. This information should be combined with an analysis of the cultural context of our communities, and with an examination of how interactive digital data displays designed to impart green infrastructure to museum visitors fit within that context.

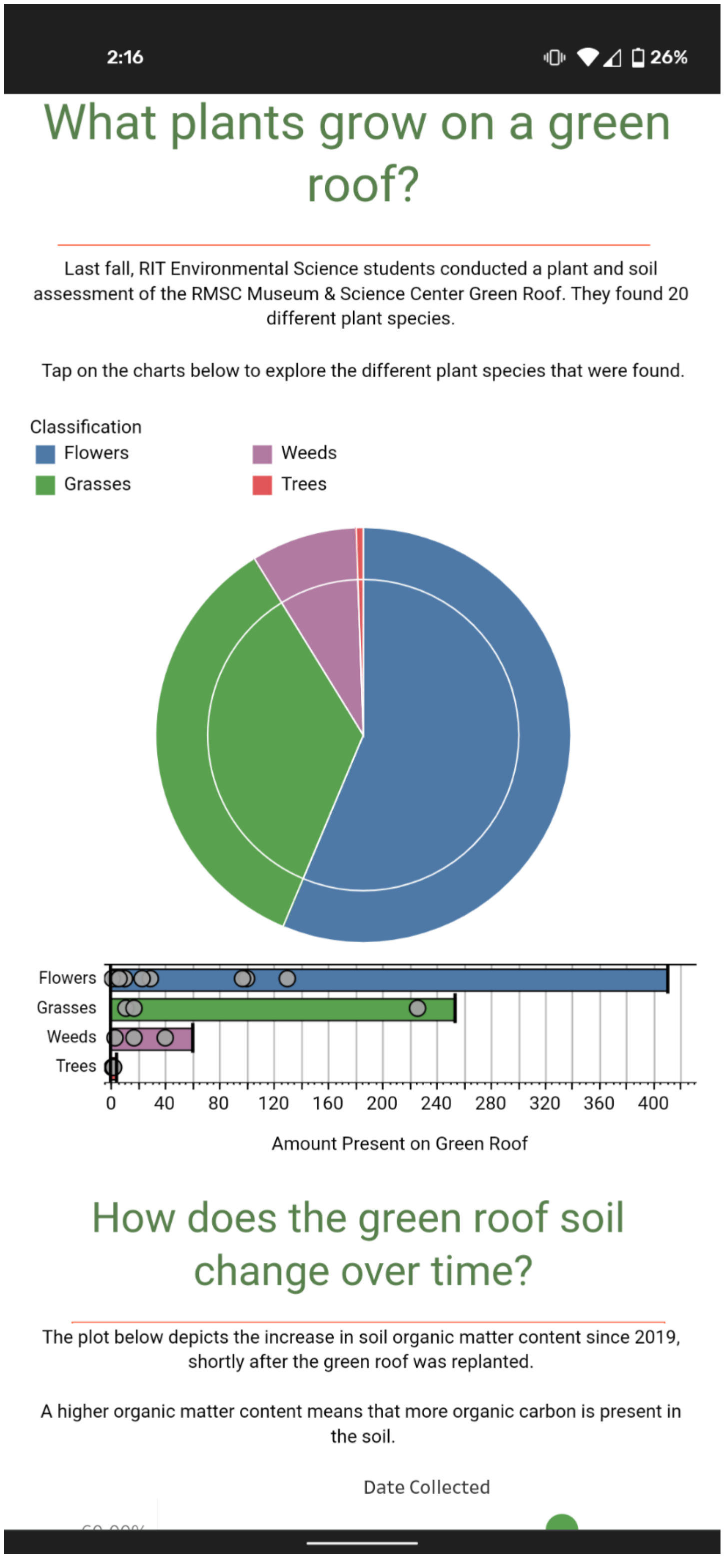
Conclusion

This thesis is intended to demonstrate how scientific data can be shared with the public through a museum setting using two different methodologies for creating data visualizations that are informative and interactive. The three outcomes that I intended to achieve were as such: to share data from the green infrastructure showcase; to visualize and interpret scientific data for visitors to the museum; and to show how data may promote behavioral change. The visualization methods I have initiated would provide a legitimate means of sharing the data collected by GIGP teams with our community and provide, on their own, information that is not currently available in the museum exhibit space. With the addition of an appropriate amount of interpretation, the data would move from merely measurement to a prompt for visitor engagement. Data that is interactive and positioned with reference to the viewers' daily lives becomes "living, breathing data," which I define as quantitative information presented as a series of data visualizations that visitors can interact with. Such data can foster visitor engagement and may motivate visitors to change their behavior in order to be responsible stewards of the environment. To ensure a more sustainable and climate resilient future, we must shift our behaviors and implement green infrastructure for the health of our urban environments. Living, Breathing Data approaches this shift by prototyping an example of how public understanding of green infrastructure can be improved via data sharing and interpretation.

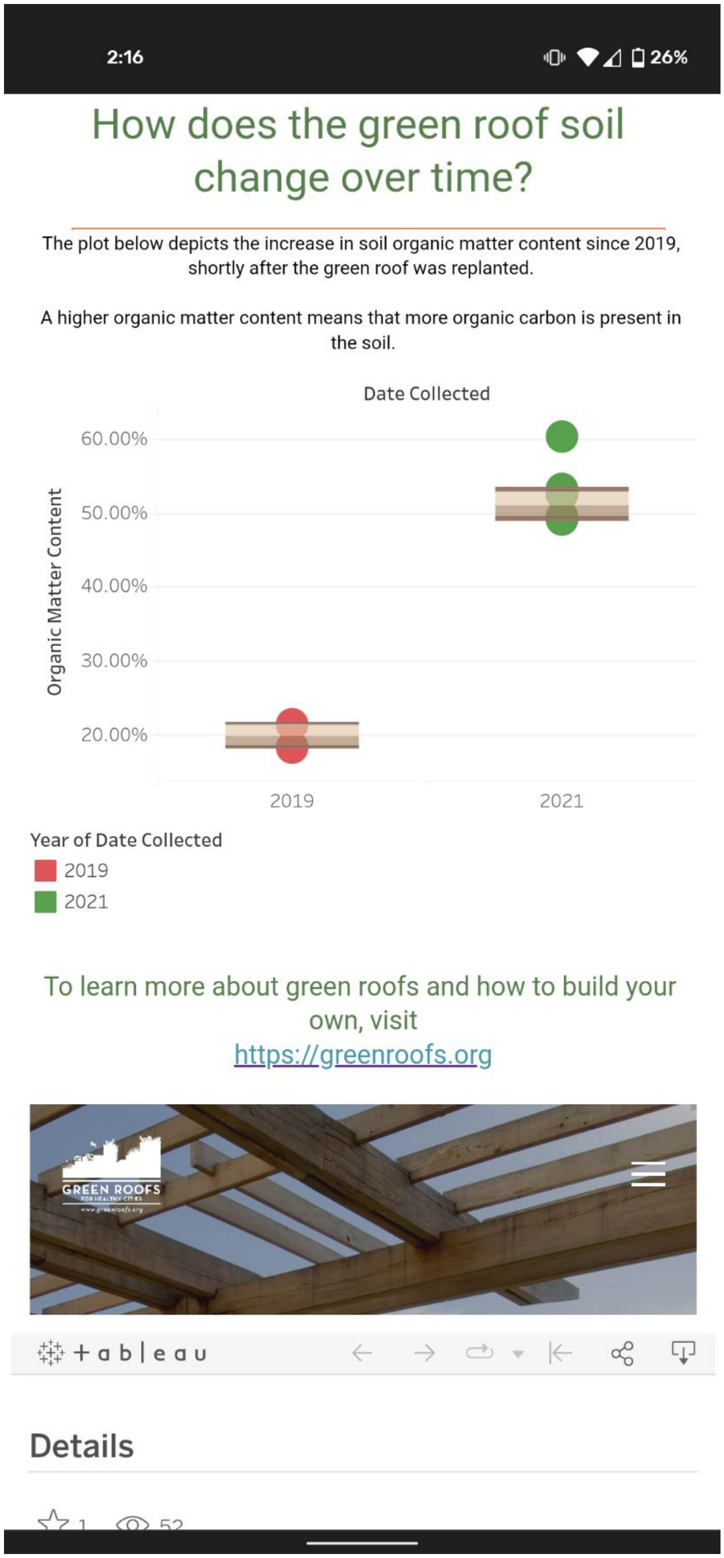
Appendix

Item A: Green Roof Plant and Soil Assessment Dashboard (1)

Item B: Green Roof Plant and Soil Assessment Dashboard (2)



Item C: Green Roof Plant and Soil Assessment Dashboard (3)



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