Escaping Flat Landscapes: Landscape Visualization and Land Conservation Communication

by

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Abstract

Land trusts are organizations that protect land from development through the acquisition of ownership or conservation easements on important privately owned property. As of 2020, they are responsible for the protection of over sixty-one million acres of land throughout the United States. Land trusts use online maps for a variety of communication purposes associated with existing conservation values and potential threats to these values. Advances in digital cartography have made online two (2D) and three-dimensional (3D) maps accessible to an expanding audience for use in a growing number of fields. For example, the emergence of digital twins and 3D modeling has transformed urban planning and design. However, the potential role of 3D modeling in rural planning and for land conservation applications hasn't been explored to any substantial degree. With that as context, this study evaluated the effectiveness and usefulness of 2D and 3D maps to address land trust communication purposes at different geographic scales (parcel and landscape).

Phase 1 of the research involved a survey soliciting input from land trust personnel throughout the United States on the potential communication use cases of maps and conservation values featured on maps. Considering the results of Phase 1, Phase 2 of the research involved developing 2D maps and 3D scenes for a watershed in central Maryland that was the geographic area of interest for a hypothetical land trust (the Wolfsville Land Trust) and then engaging land trust personnel throughout the United States to participate in remote testing of these maps and scenes to evaluate map effectiveness and map usefulness.

The results of the study showed that there was not a statistically significant difference in map effectiveness based on (1) map dimensionality, (2) map scale, or (3) the interrelationship between map dimensionality and scale. However, there was a statistically significant preference for 3D maps over 2D maps to address the land conservation communication purposes evaluated.

The results are discussed for their implications for future land trust communication needs, including the potential to leverage future technological

advancements to better address these needs. Strengths and limitations of the research are noted, along with recommendations for further refining future research by evaluating certain types of tasks independently from one another and by considering other formats and styles of 2D and 3D maps.

Acknowledgments

This one is for Lorraine.

I would like to thank my mother, Lorraine Wolf, and my father, Walton Wolf, for instilling in me a curiosity in all things and a lifetime of support in furthering my education. It has been decades since you left, but all my educational accomplishments are attributable to the foundational support I received in my youth. So, thank you.

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I'd like to thank my son Chris for helping me work smarter, not harder, by automating some key processes. I'd like to thank Chris and his brothers Kelly and Brett for being funny, smart, and patient with me on so many occasions.

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John Wolf

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Chapter 1: Introduction

Research Motivation and Scope

In the United States, land conservation can take many forms. Private land conservation organizations, or land trusts, play a critical role in the permanent protection of land through land acquisition or through the donation and/or purchase of conservation easements. According to the 2020 National Land Trust Census, land trusts have protected more than 61 million acres – an area larger than all National Parks combined (Land Trust Alliance 2022c).

The role of land trusts in land conservation has been recognized in national initiatives, including President Biden's America the Beautiful (AtB) program. The AtB campaign aims to conserve 30% of the Nation's land and water resources by the year 2030 (U.S. Department of the Interior 2022). AtB contains eight key principles to guide land conservation efforts. Several of these principles directly apply to land trust conservation actions and, by extension, to this research.

Table 1. Guiding Principles of the America the Beautiful Initiative. (The White House 2021)

Pursue a Collaborative and Inclusive Approach to Conservation
Conserve America's Lands and Waters for the Benefit of All People
Support Locally Led and Locally Designed Conservation Efforts
Honor Tribal Sovereignty and Support the Priorities of Tribal Nations
Pursue Conservation and Restoration Approaches that Create Jobs and Support Healthy Communities
Honor Private Property Rights and Support the Voluntary Stewardship Efforts of Private Landowners and Fishers
Use Science as a Guide
Build on Existing Tools and Strategies with an Emphasis on Flexibility and Adaptive Approaches

Land trusts vary considerably not only in their geographic area of interest but also in staff support. Many are all-volunteer organizations, while some have staff of over 100 personnel. Many originate around a short-term desire to protect a specific place from development but then evolve into organizations with lasting conservation contributions that complement governmental land protection programs.

Land trusts use maps for many purposes, both to address internal operational needs as well as external communication to their stakeholder audiences. Maps include both hard-copy printed materials and increasingly, interactive web maps. To date, minimal three-dimensional (3D) mapping has been pursued by land trusts – particularly in an interactive, web-based format.

In recent years there has been a proliferation in 3D geographic information systems (GIS) across many fields and topical domains (Heidelberg 2021), including environmental applications. However, this trend has yet to translate to the land conservation domain despite the growing use of GIS among land trusts. This research will explore the potential for leveraging 3D GIS to address the communication needs of land trusts. Doing so will help clarify the potential role for the technology in supporting the land trust role in achieving the ambitious goals of America the Beautiful.

Research Context

This research is situated within the theoretical nexus of landscape science, data visualization, land conservation, interaction design and user experience. As such it is inherently transdisciplinary and draws from seminal works in the structural/visual representation of landscapes, their ecological significance, and visual communication.

Three-dimensional representations of urban areas have been used by architects and landscape architects for decades. The visual aspect of urban landscapes as a planning focus gained stature with Lynch’s 1960 “The Image of the City”, in which he argues that people create mental maps of the city based on the visual qualities of paths, edges, district, nodes and landmarks (Lynch 1960). Higuchi extended this paradigm to landscapes, demonstrating how the visual perception of planes and space is used to characterize types of landscapes (Higuchi 1983). Tuan connected the visual landscape to human geography, noting how visual elements contribute to a sense of “place” (Tuan

1977). More recently, the visual landscape has been connected to tourism, as proposed by Urry's conceptual model of the "Tourist Gaze" (Urry & Larsen 2011).

Landscape structure also contributes to an understanding of the ecology of place. Beginning with Aldo Leopold's classic work "A Sand County Almanac", place-based values and ethics drive much of modern-day conservation activities (Leopold 1966) and, to some extent, place-based ecological research (Billick & Price 2010). Place-based ecology is at the heart of modern ecological planning, for which Ian McHarg first established a systematic approach to landscape planning that became the precursor to modern GIS (McHarg 1969). The integration of "the people of the place" into environmental planning has led to establishment of the modern field of geodesign (Steinitz 2012). Geodesign is a maturing field that combines the design characteristics of landscape architecture with spatial science and technological advances. These characteristics overlap with the needs of modern-day place-based conservation.

Finally, the field of visual communication is itself a transdisciplinary and holistic branch of knowledge. It combines communication science with graphic design and data and information visualization. This research connects to visual communication on multiple levels. At its most fundamental level, visual communication draws from the data abstraction primitives common to all graphic design problems. For example, any graphic or cartographic product is a compilation of visual variables – a concept first articulated by the French cartographer Jacques Bertin in his classic *Semiologie of Graphics* (1983). Graphic primitives are important in any visual communication project, but their compilation and organization into a coherent map, illustration or diagram becomes a design problem. Effective design draws from principles articulated from some of the modern-day masters in the fields of data and information visualization (see, for example, Tufte 1983 and 1990, Cairo 2013 and 2016, Few 2006, and Munzner 2015).

Interactive 3D models have provided the representation of landscape structure in support of the rising relevance and interest in "digital twins" (Bay 2018). To date, the digital twin concept has primarily focused on the built environment. This research begins to extend the digital twin concept to the rural countryside and natural landscapes and applies the concept in the context of land conservation communication.

Research Questions and Hypotheses

This section provides the research question and hypothesis statements to be addressed through this research. The research questions investigated relate to the effectiveness and perceived usefulness of 3D maps for addressing land trust conservation communication objectives.

Usability of a system in the context of map interface designs typically refers to efficiency, effectiveness, and satisfaction (See Neilson 1994 for an overview of usability and Coltekin et al 2009 for an explanation in the context of map interface design). Efficiency is typically measured in terms of how quickly tasks are completed. Effectiveness refers to whether the task is completed successfully/accurately. Satisfaction deals with the user's attitude and preferences. Somewhat related to satisfaction, perceived usefulness is "the degree to which a person believes that using a particular system would enhance his or her job performance" (Davis 1989, Hussain et al 2016). In that sense, it is a belief by the user that the system enhances job performance.

For purposes of this research, the "job" of the map is to achieve one or more communication objectives of the land trust. This research focuses on (1) effectiveness, or whether the user can extract the correct information from the map in order to successfully complete a task, and (2) the perceived usefulness of the map in the context of land trust communication objectives. Note that perceived usefulness is a "users' subjective assumption and opinion of the system and does not necessarily reflect objective reality" (Matusiak 2012). As implemented in this study, the perceived usefulness is a self-rating (using a five-point Likert scale) based on the user's encounter with the map.

For purposes of this research, tasks for interpreting land trust conservation values are drawn from established map task typologies. Therefore, successful task completion is an objective measure that can be quantified. It is within that context that map effectiveness is evaluated.

Research Question 1 - Does map dimensionality impact the success rate in which land trusts are able to communicate conservation values given identified communication objectives?

Research Question 2 – Does map scale impact the success rate in which land trusts are able to communicate conservation values given identified communication objectives?

These research questions will be addressed based on hypotheses relating to map effectiveness.

Map effectiveness.

For research question 1, the independent variable is map dimensionality, and the dependent variable is map effectiveness. Therefore, the null hypothesis is as follows:

H_0: Dimension (two-dimensional vs three dimensional) will have no significant effect on the effectiveness (as measured through the successful responses to task-based questions) of maps for communication purposes.

Accordingly, the hypothesis for map dimension is:

H_1: Map dimension will impact the success rates of participants addressing map tasks associated with land trust conservation purposes.

For research question 2, the independent variable is map scale and the dependent variable is map effectiveness. Therefore, the null hypothesis is as follows:

H_0: Map Application Scale (landscape vs parcel) will have no significant effect on the effectiveness (as measured through the successful responses to task-based questions) of maps for communication purposes.

Accordingly, the hypothesis for map scale is:

H_1: Map scale will impact the success rates of participants addressing map tasks associated with land trust conservation purposes.

The two independent variables may also have interaction effects. In other words, map scale (landscape or parcel) and map dimensionality (2D or 3D) may be related in terms of their predictive impact on map effectiveness. For purposes of this research the null hypothesis is as follows:

> H_0: Dimension and map application scale interaction will have no significant effect on the effectiveness as measures through the successful completion of tasks of maps for communication purposes

The corresponding hypothesis for the potential interaction effect is:

> H_1: There will be a relationship between dimensionality and scale for map tasks associated with land trust communication purposes

Map usefulness.

For purposes of this research, map usefulness is concerned with whether the map reader perceives the map product to be useful for a specific purpose. Since this is based on the opinion of the individual the results are inherently qualitative. It is a subjective measure that is measured through nominal or ordinal scale ratings.

Research Question 3 - Does map dimensionality influence the perceived usefulness of maps to address land conservation communication objectives.

> H_0: There is no relationship between map dimensionality (two-dimensional and three-dimensional) and perceived map usefulness for land trust communication purposes.

Accordingly, the hypothesis for map usefulness is:

> H_1: Participants will prefer 2D or 3D maps for addressing land trust communication purposes.

Dissertation Organization

This dissertation is organized based on an evaluation of land conservation mapping needs and the assessment of the utility of 3D mapping to address communication objectives. This introduction establishes the context for the research, the research questions, and the hypotheses to be tested. A literature review is presented in Chapter 2, which situates the context of the research among landscape science, art and communication, visualization, landscape modeling, established landscape visualization research methods, and existing applications of landscape visualization. The literature review concludes with an overview of the land trust community and their use of maps.

Chapter 3 contains the methods and results from Phase 1 of the research, which consisted of a baseline study focused on confirming assumptions related to land trust conservation values, use of maps for communication purposes, and the potential use of maps to communicate landscape change. This was accomplished via a survey of land trusts nationwide. The results of the baseline study described in Chapter 3 were used to establish the research context and instrument used in Phase 2 of the research. Drawing from lessons learned from the land trust survey, Chapter 4 describes the steps taken to develop interactive 3D representations of landscapes. A hypothetical land trust case study was used as the focus for place-based landscape modeling. The resulting interactive web scenes were used for Phase 2 of the research, which is described in Chapter 5. Phase 2 involved testing the research hypotheses through an online survey aimed at land trusts nationwide. The survey asked land trust personnel to answer a series of questions related to map effectiveness and map usefulness in response to a series of web mapping scenarios in 2D and 3D. Finally, Chapter 6 discusses the results of the research from the perspective of map effectiveness, map usefulness, experimental design, and landscape visualization methods.

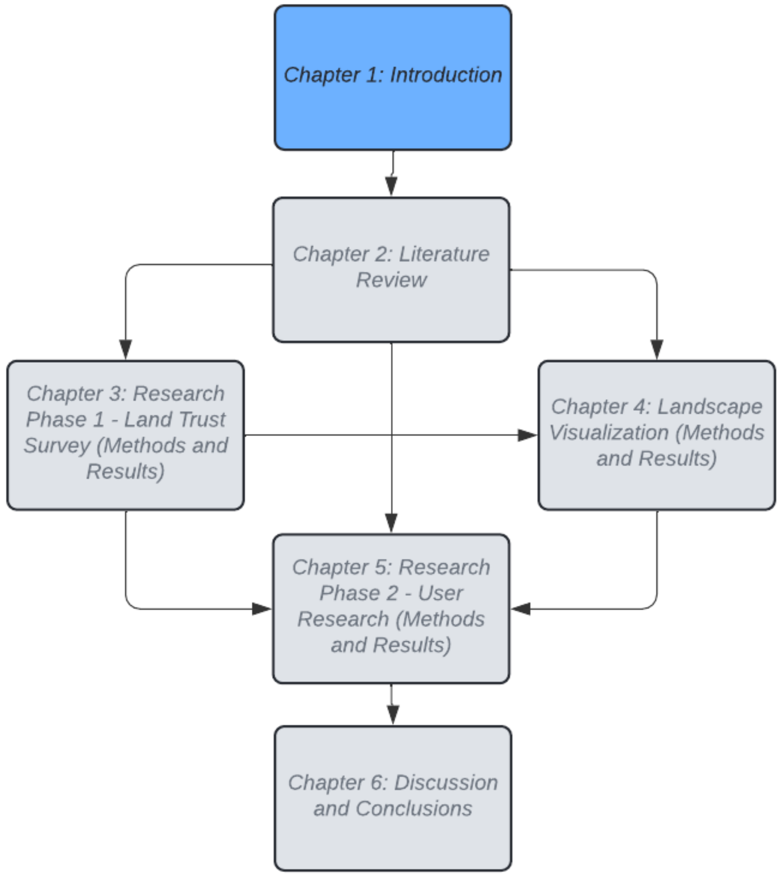
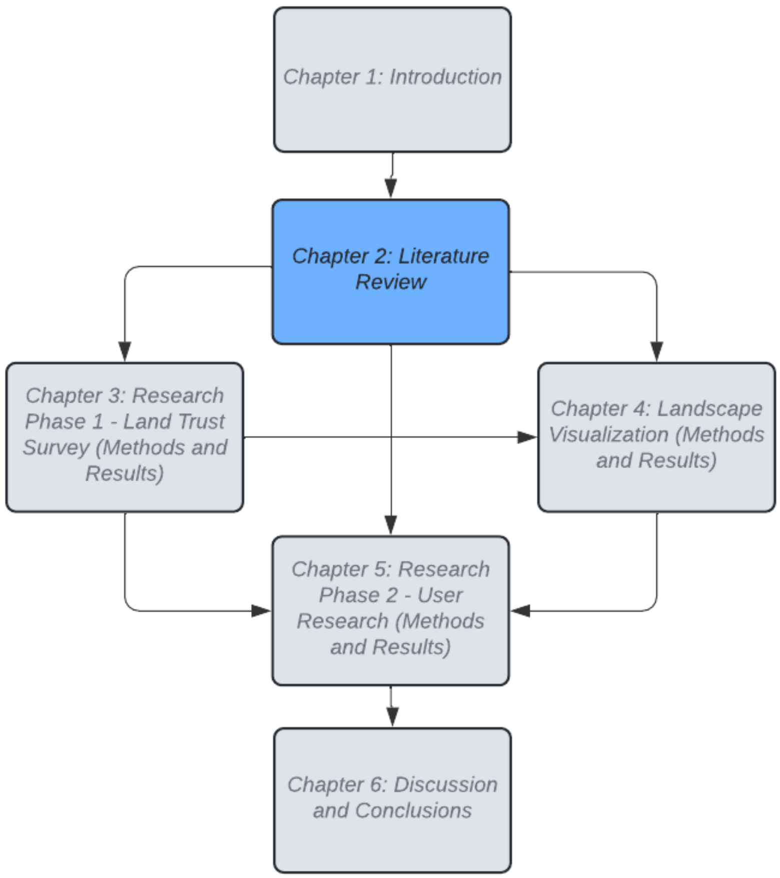


Figure 1. Dissertation Chapter Organization

Chapter 2: Literature Review

The purpose of this chapter is to review the literature relating to this research, including history and significance of the issue, landscape modeling, landscape visualization research, and land trust and land conservation mapping.



History and Significance of the Topic

Landscape in Science, Art, and Communication

Landscape as place. The Greco-Roman mathematician and geographer Claudius Ptolemy distinguished between geography, as the study of the entire world, and chorography, which was the geographical description of regions. In addition to the distinction of "scale" (world as opposed to region), "chorography" evolved as a descriptive term that emphasized communication of qualities of place as opposed to the quantification of space (O'Sullivan, 2011; Rohl, 2012). The qualities of chorographic place emphasized by Ptolemy had practical implications as they extended representations of regions (or landscapes) from mathematical constructs (i.e., maps depicting the technical surveying tasks of geography) to artistic or graphical realms (Berggren & Jones, 2000; Gehring, U., 2015). The chorographic approach allowed for a visual reflection of human and cultural activities including the potential for a sense of "belonging" within a setting (Pietroni, 2017).

Although the usage of the term chorography has evolved (and declined) over the past two centuries, the distinction of the mathematical depiction of space versus the experiential representation of place is important in a wide variety of fields and applications (Hunziker, Buchecker, & Hartig, 2007; Tuan, 1977). Today, digital chorographies (or place-based spatial narratives) serve as a hybrid model of spatial representation that can serve as a powerful tool for communicating natural and cultural issues (Koeck & Warnaby, 2015).

Landscape science, ecology, and planning. *Landscape science* as a discipline focuses on the relationship between people and the environment, with an emphasis on how people are changing the landscape and the environmental impacts that result (Robinson & Carson, 2013). It is an inherently multidisciplinary field as humans impact ecological processes at multiple scales and in numerous ways. Many disciplines connect to landscape science in their fields of study and the pursuit of discipline-specific objectives, including ecology, forestry, agriculture, landscape architecture, planning and urban development, archeology, and even psychology. Collectively, these disciplines include both natural and cultural components, and their attention frequently focuses on impacts to the landscape from human decisions. As such, they share common communication objectives which in some cases can be addressed through graphical representations aimed at addressing the needs of various stakeholders.

Increasingly, the focus is on anticipatory science and understanding the role science plays in the consequences of intended or unintended changes (Bradford, Betancourt, Butterfield, Munson, & Wood, 2018). In recent years there has been recognition that the field of landscape science is *transdisciplinary*, in that successful approaches to evaluating the impacts of change require collaboration across disciplines because of the many cross-cutting impacts of ecosystems and their management (Antrop, 2000). Ultimately, these approaches will contribute to the field of translational ecology by "connecting end users of environmental science to the field research carried out by scientists who study the basis of environmental problems" (Schlesinger, 2010). Accordingly, there will be a growing emphasis on (1) partnerships between scientists, practitioners, and stakeholders, (2) place-based and context-specific considerations, and (3) use-driven and actionable strategies (Enquist et al., 2017). As will be discussed, landscape visualization can serve an important role to support transdisciplinary communication and to help synthesize information across topics for the benefit of a variety of stakeholders.

Landscape ecology is a somewhat more narrowly defined field that looks at the composition, structure, and function of terrestrial and aquatic features of landscapes (see Figure 2). Also interdisciplinary in scope, landscape ecology considers the causes and consequences of spatial patterns and ecological processes at multiple scales (Turner & Gardner, 2015). As a result, it provides the theoretical framework for assessing factors such as land use change, hydrologic and topographic change, and landscape disturbances in different ecological contexts (National Academies of Sciences, 2016). Increasingly, landscape ecology is focused on three- and four-dimensional spatial phenomena (Drăguţ, Walz, & Blaschke, 2010) and in many cases can provide the quantitative basis for characterizing and evaluating landscape configuration through landscape pattern metrics. As such, it can be used to summarize landscape attributes over time *quantitatively*. Comparing quantitative landscape metrics to perceived landscape values obtained through interactive landscape visualization is central to this research.

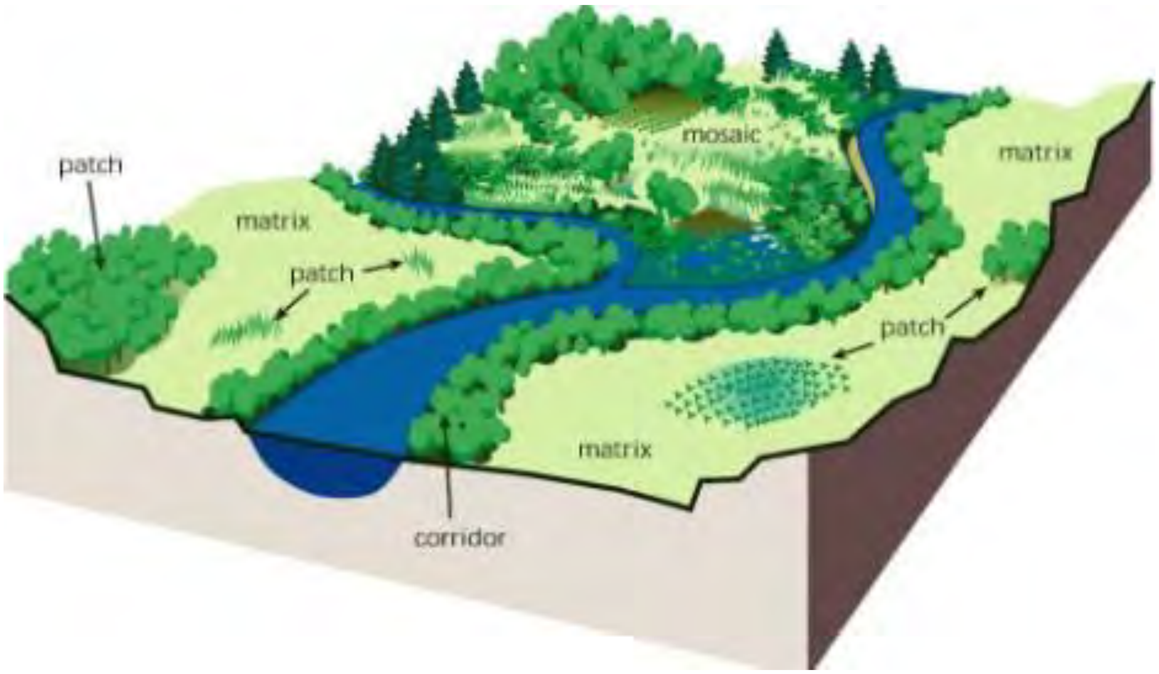


Figure 2. Landscape conceptual diagram illustrating an assortment of terrestrial and aquatic features. Image credit: FISRWG (10/1998). Stream Corridor Restoration: Principles, Processes, and Practices. By the Federal Interagency Stream Restoration Working Group (FISRWG)(15 Federal agencies of the US gov't). GPO Item No. 0120-A; SuDocs No. A 57.6/2:EN 3/PT.653. ISBN-0-934213-59-3.

From an applied perspective, there is considerable overlap between the scientific foundations of landscape science and landscape ecology, and the modern *landscape planning* applications aimed at articulating past, present and future landscape conditions under different scenarios (Helfenstein, Bolliger, Kienast, Bauer, & Clalüna, 2014). *Landscape visualization* (which will be defined more explicitly later in this chapter) has and will continue to play an essential role in engaging stakeholders in decisions affecting human uses of landscapes at multiple spatial scales over time.

Landscape science communication. Visual science communication has gained attention as an important field that complements advancements in pure and applied science. It requires a specific skill set that many scientists lack, and conversely, today's graphic designers and computer artists are often deficient in ecological science training and expertise. Also, understanding the best ways to present and communicate *data* can be a challenge for scientists and graphic designers alike (Kosara & Mackinlay, 2013).

Chappell and Hartz (2013) further call attention to the challenges of explaining science to the *public*, suggesting that neither scientists nor journalists feel that the media do a good job and that they should make better use of graphics in communication products.

Estrada and Davis (2015) identify key impediments to the effective use of visual elements in science communication products, including (1) treating them as an afterthought as opposed to being integrated through the scientific process and (2) failing to identify the target audience and their requirements adequately. These concerns apply regardless of whether the audience is composed of scientists, decision-makers, or local citizens in a planning process. As will be discussed, an understanding of the visual literacy of stakeholders is key to developing effective visual communication products. When designed well, visual products can enhance public understanding of complex ecological and socioeconomic phenomena and the impacts of environmental management proposals (Zimmerman, Akerelrea, Smith, & O'Keefe, 2006).

Ecosystems are complex. The landscapes and seascapes that make up these ecosystems vary widely in composition and structure with substantial variation in the natural and cultural features they contain. This variety is sometimes associated with the degree of "naturalness" or "disturbance" of the natural physiographic setting and its corresponding placement along an urban-rural landscape gradient associated with population and development. In science communication, the tendency has been to favor generic or representational landscapes as opposed to specific, place-based depictions (Hansen & Machin, 2013). The resulting abstract representations are used to communicate general concepts, but the lack of real-world context results in emphasis on "space" over "place".

A frequently used approach is to employ *conceptual diagrams* (see Figure 3), or "thought drawings", to communicate landscape science concepts in an intuitive, graphical manner (University of Maryland - Center for Environmental Science, n.d.).

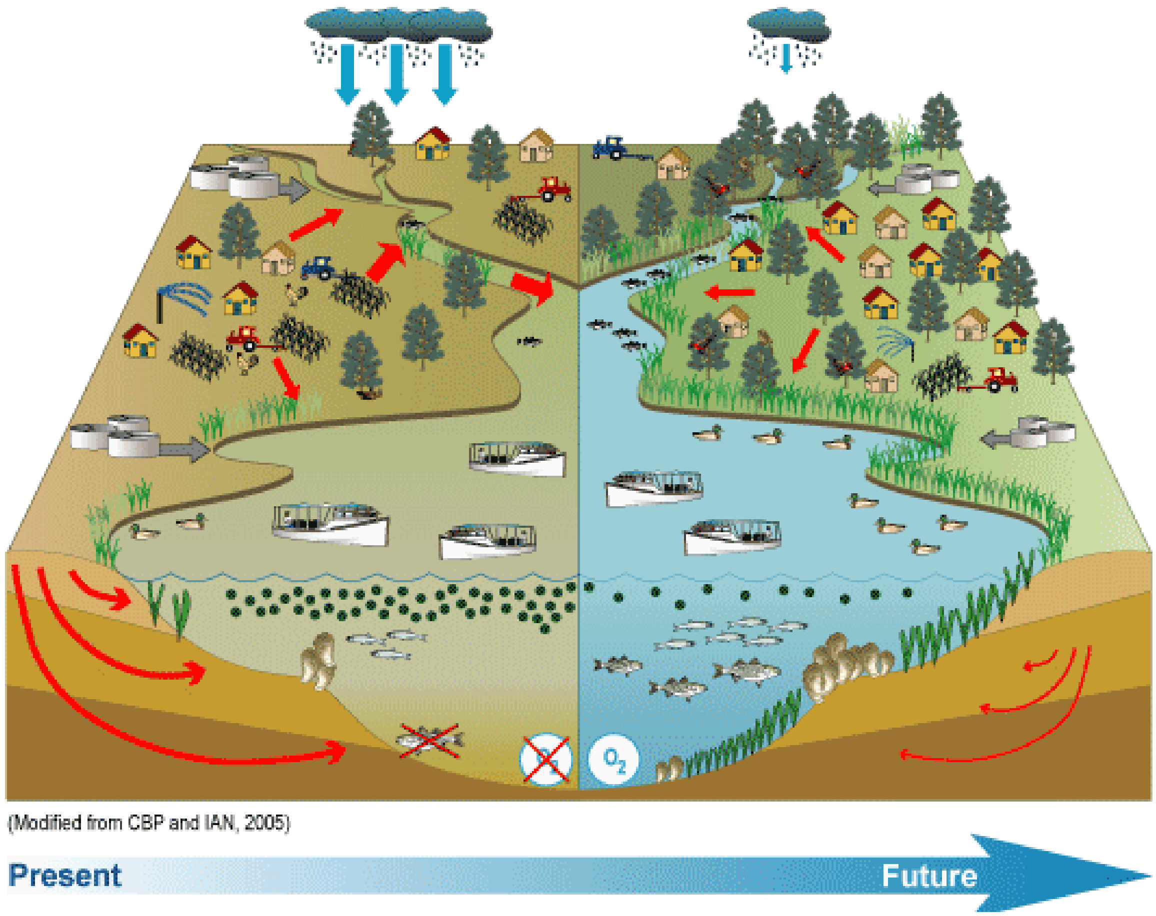


Figure 3. Conceptual diagram of a hypothetical landscape indicating current and potential conditions as a result of management actions and land use change. (Image credit: Jane Thomas, Integration and Application Network (ian.umces.edu/media-library) is licensed under (CC BY-SA 4.0)

Although generic conceptual diagrams have many benefits, research has shown that communication with stakeholders is enhanced when locally relevant examples based on specific site characteristics are utilized (Sitas, Prozesky, Esler, & Reyers, 2014). In the real world, landscapes are valued in different ways by people who experience them from different perspectives. For example, an individual's concept of *environmental sustainability* is influenced by a *personal* cultural interpretation of the values that should be sustained in a given region, which are in turn influenced by the cultural identity of that region (Stephenson, 2008). Complementing abstract representations with visualizations of recognizable settings with local data or information can increase personal salience and connection to a particular place (Burch, Sheppard, Shaw, & Flanders, 2010; Sheppard, 2005; Daniel & Meitner, 2001).

Landscape models can extend and refine impressions gained through conceptual models or thought drawings by connecting the abstract to the actual. Three-dimensional landscape models are used to present a more realistic depiction of a particular place and therefore are usually more accessible to multiple audiences familiar with that place (Entwistle & Knighton, 2013). Landscape models, landscape visualization, and associated decision-support tools have become common in landscape planning because of the value they add to the process, often enabling an audience to understand, and react to, the impacts of change to the landscape (Walz et al., 2008).

However, all landscape models, visualizations, and maps are abstractions of reality. The unstructured development and use of landscape visualizations can impact their effectiveness in communication, planning, and decision-making (Sheppard, 2001). Equally important is the *context* in which they are used (Neto, 2006), as communication occurs through a variety of formats, media types, and interaction settings. Finally, these same concerns impact landscape visualization *research* methods. These opportunities and limitations will be explored in more detail later in this chapter.

Historical Milestones in Landscape Visualization

This section focuses on the historical evolution of landscape visualization in science and art, with a focus on three-dimensional representation through non-digital and digital media formats.

Pictorial approaches to 3D landscape representation. Although landscape painting has been around for millennia, deliberate attempts to represent the third dimension in two-dimensional space are (relatively) modern. The seventeenth century was a period of noteworthy creative exchange between scientific and artistic thinkers (Gehring & Weibel, 2015). During this period landscape painters integrated topographic elements and chorographic views, simultaneously combining artistic approaches to space (by incorporating map-like features in the background) and place (through chorographic views of people, places, and things in the foreground). These resulting combinations of map and images in the same painting (along with a variety of visual clues drawing from depth perception/cue theory, atmospheric effects, and other techniques), created an illusion of three- and sometimes four-dimensionality (by incorporating actions from different places and times simultaneously) (Gehring, 2015).

Peter Snayers, a Flemish painter known for his topographic battle scenes, used this technique to create a space continuum that blended people/action in the landscape foreground with the muted colors of the countryside in the background (see Figure 4). This technique was particularly popular in reconstructing battle scenes in realistic reproductions, with the background elements becoming more schematic with distance towards the horizon (Pfaffenbichler, 2015).

Figure 4. Peter Snayers' The Archduchess Isabella at the Siege of Breda. Note chorographic foreground elements with topographic (map-like) background elements. (Image credit: Used by permission of the ©Photographic Archive Museo Nacional del Prado)

In the late eighteenth century, panoramic paintings emerged. Typically, a panoramic landscape was shown on a wide, curved surface that provided the viewer with a sense of immersion. The term panorama first appeared in 1792 in connection with Robert Barker's detailed paintings of the London skyline. Each painting was a picturesque view of the realistic London landscape that included the horizon and sky (Patterson, 2000).

Panoramas continue to be a popular approach to representing landscapes, particularly in mountainous regions and for tourism-related products. H. C. Berann developed a series of cartographic panoramas for the U.S. National Park Service as well as pictorial representations of European mountain ranges used in multiple Winter Olympic competitions (see example in Figure 5). Typical characteristics of these panoramas include simulated three-dimensionality, integration of horizon-sky and terrain, and detailed and realistic surface features (Patterson, 2000).

Figure 5. H.C. Berann's panoramic painting of Yellowstone National Park. (Image Credit: National Park Service, accessed March 19, 2022 from https://www.nps.gov/carto/app/#!/maps/categories/12)

Tom Patterson, formerly of the National Park Service, identified a series of techniques used by the creators of panorama paintings to enhance the perceived 3D experience (Patterson, 2000). Many of these techniques also apply to computer-generated 3D landscape visualization.

Two-dimensional artistic techniques have also been applied to give the impression of three-dimensionality. Many of these relate directly to the depiction of terrain, including the use of contour mapping, hachures, shaded relief, hypsometric tints, and cross-sections (Desimini & Waldheim, 2016). Terrain representation in two dimensions is a cartographic specialty in and of itself and is outside of the scope of this dissertation. However, a summary of three-dimensional techniques and lessons learned from cognition and graphic design will be explored later in this chapter.

In addition to panoramic paintings, considerable research has focused on panoramic photographs and how people interact with them and what captures their attention. For example, Dupont, Antrop, & Van Eetvelde (2014) found that panoramic photographs are observed more extensively than other photographs and that the viewer is likely to extract more information as a result. This suggests that a landscape image may enhance recall when presented as a panorama. In follow up studies they found that heterogeneous (i.e., diverse) landscapes encourage more visual exploration and hold the attention of the viewer longer (Dupont & Van Eetvelde, 2014; Dupont, Ooms, Duchowski, Antrop, & Van Eetvelde, 2017). The same studies indicated that more complex urban landscapes generated more extensive and dispersed exploration of the scenes, but if the landscape scene did not include buildings, other factors influenced viewing behavior. In all cases, viewer interest seemed related to scene complexity.

Physical/structural approaches to 3D landscape representation. One of the earliest attempts to integrate the visual with the physical qualities of three-dimensional space came with the invention of the diorama. Frequently recognized as one of the pioneers of modern photography, L. J. M. Daguerre was also known as the perfecter and promoter of the diorama (Gernsheim, H. & Gernsheim, A., 1968), which combined techniques of opaque and translucent painting, physical models, and the manipulation of light to provide a 3D experience for the viewer (Dead Media Archive, 2010).

Dioramas evolved to become popular exhibits in museums and were frequently used to communicate environmental or natural history storylines (Rasmussen, 2018). Examples include the famous natural history exhibits in the American Museum of Natural History in New York and the natural history dioramas of the Smithsonian National Museum of Natural History in Washington, D.C.

Perhaps the best examples of the amalgamation of dioramas and landscape science are the Harvard Forest dioramas, which provide a fascinating overview of landscape history and land use change in central New England (Foster & O'Keefe, 2000). The Harvard Forest dioramas (see Figure 6) combined solid models in the foreground with a variety of textures and painted effects to provide a 3D experience aimed at environmental education. Many of the Harvard dioramas show the same landscape at various points in time, showing different forest successional stages and human uses of the landscape including cultural and technological artifacts of the day.

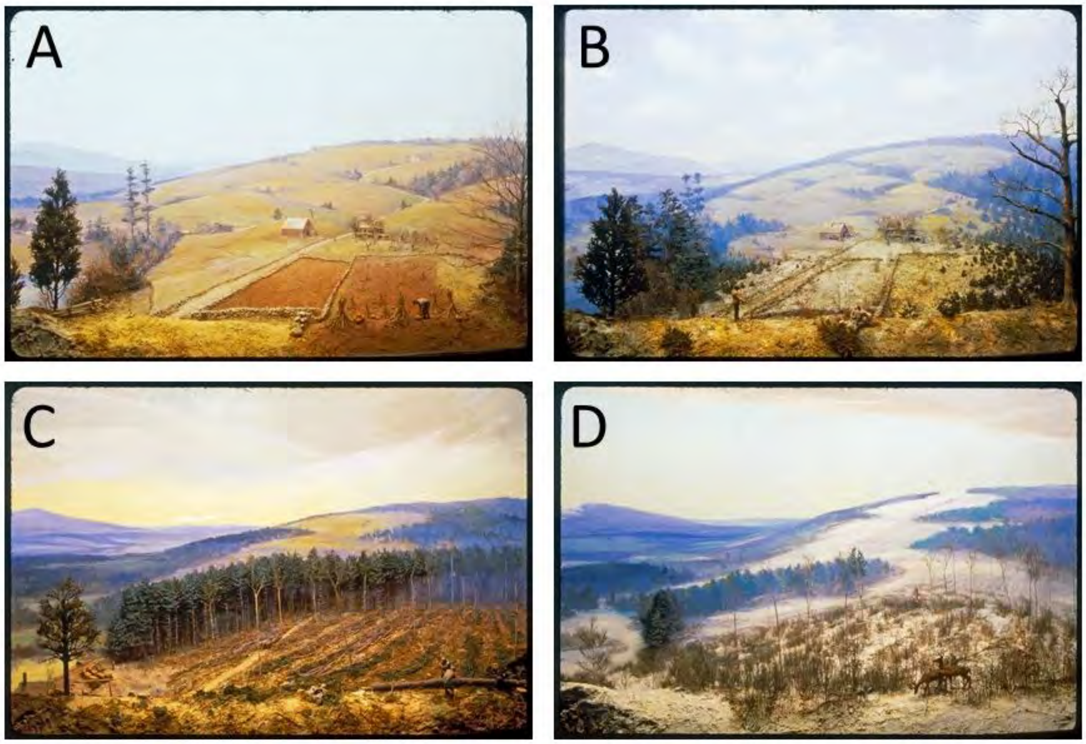


Figure 6. Examples of the Harvard Forest dioramas showing changes in the New England landscape (Image Credit: "Landscape History of Central New England" by Harvard Forest is licensed under CC BY-ND 2.0).

The subject of museum landscape dioramas is not limited to natural resource-based communication. They have been and continue to be popular approaches to communicate historical events from a landscape perspective. For example, the cyclorama highlighting the Battle of Gettysburg at Gettysburg National Historical Park (Figure 7) in Pennsylvania combined physical and pictorial diorama elements in a cylindrical format that resulted in the viewer being surrounded by the battlefield action (Brenneman & Boardman, 2015).

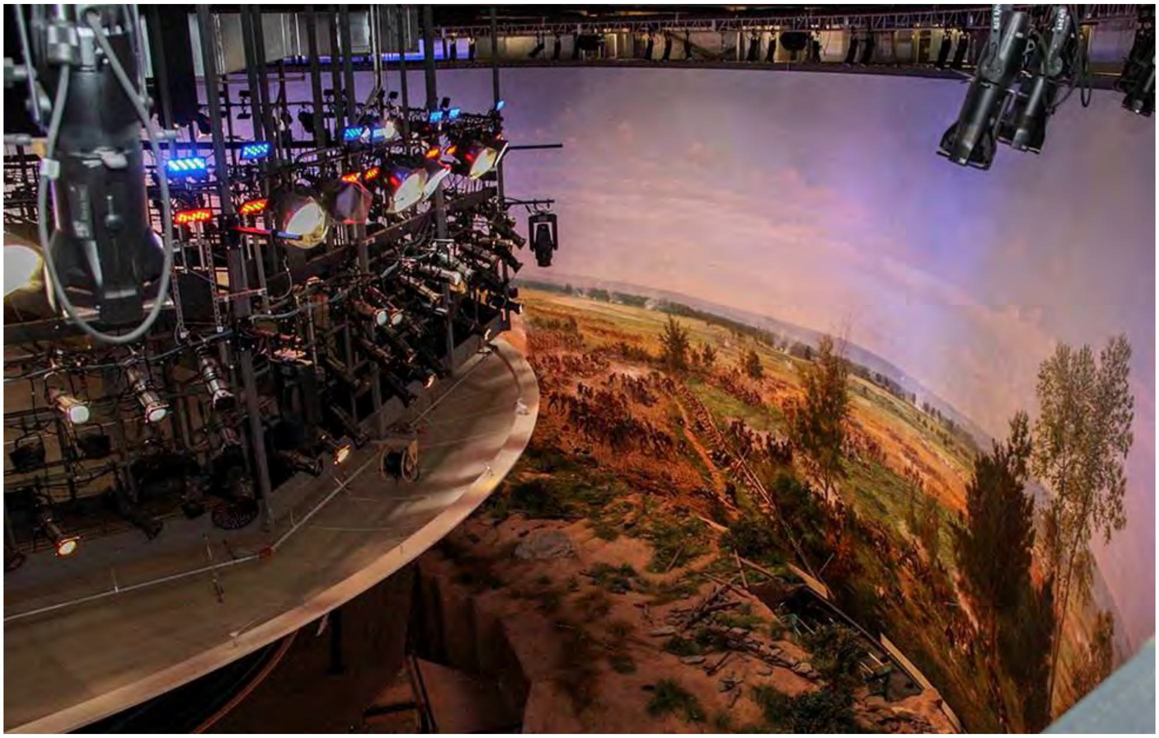


Figure 7. Gettysburg Cyclorama. (Photo credit: "The painting and diorama seen from above", National Park Service Photo, Gettysburg National Military Park).

In many ways, dioramas represent a transition from the purely pictorial approaches used in landscape paintings and panoramas to physical representations of 3D space. Throughout the latter half of the 19th century and continuing to this day, physical models of terrain have been used for place-based representations of landscapes. Many of these were developed to support military purposes. Of particular significance was the emergence of Swiss terrain models developed, in part, due to the mountainous terrain of Switzerland and the lack of useful topographic maps (Institute of Cartography and Geoinformation, ETH Zurich, 2018). Throughout the 20th century various techniques were developed to model terrain in physical space, including plaster models, pantographs (which guided a milling cutter over a block of plaster), pressing machines (Wenschaw method), and the still common thermoplastic relief models created through vacuum forming techniques (Institute of Cartography and Geoinformation, ETH Zurich, 2018). Vacuum forming techniques to create 3D physical models can result in highly accurate and precise raised-relief maps (Higgins, 2011).

Closer to home, and perhaps a harbinger of the transition from physical models to digital representations, was the Chesapeake Bay Hydraulic model built on Kent Island, Maryland in the late 1970s (The Center for Land Use Interpretation, 1998). The Chesapeake Model was created as a tool to improve the understanding of the physical dynamics of the Chesapeake Bay. It was one of many large-scale physical models of waterways constructed by the U.S. Army Corps of Engineers during the 1950s and 1960s. Although the Chesapeake model was intended to help with the understanding of how pollution and natural events impacted the Bay, it was fraught with mechanical and environmental problems from the time it was completed. Costs of operating the model became prohibitive, and it was unable to compete with the advancements in computer modeling that were emerging at the time.

In recent years there has been a growing interest in leveraging digital technology to augment the physical environment. For example, digital sand table technology (Figure 8) has been used to generate terrain models that conform to real or imagined landscapes. Essentially an augmented reality (AR) application, digital sand tables combine sandboxes, projected light or imagery, and digital elevation models to create a tactile learning environment that has been used in both military and educational applications.

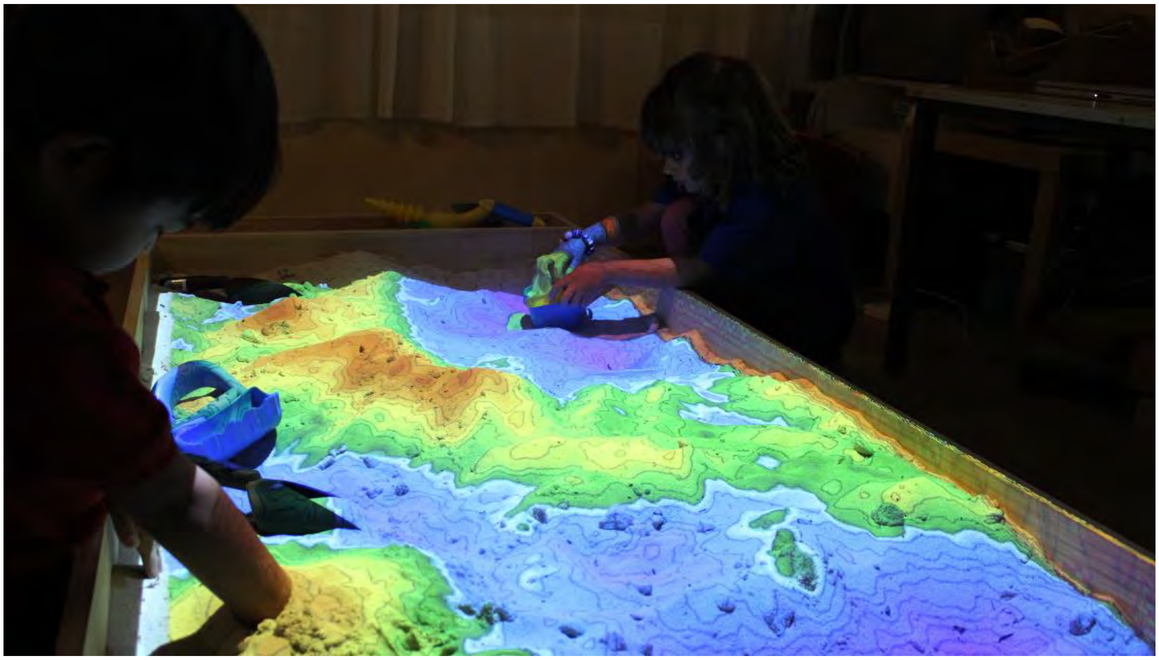


Figure 8. Augmented reality sandbox built for the Bold Park Community School, Perth Australia. (Accessed March 21, 2019, from http://idav.ucdavis.edu/~okreylos/ResDev/SARndbox/LinkExternalInstallations.html)

Digital approaches to 3D landscape representation. Three-dimensional modeling software is now commonly used to represent architectural plans, existing and future landscape conditions/scenarios, and building information models. Programs such as Sketchup, AutoCAD, Microstation, TurboCAD, Blender, and others are commonly used for 3D representation of the built environment. Many of these programs permit the creation of 3D visualizations that can be experienced through multiple viewpoints and even walkthroughs (Gill, Lange, Morgan, & Romano, 2013). However, for the most part, these programs do not directly incorporate geo-referenced data, making the creation of landscape features a mostly manual (as opposed to data-driven) task.

Geographic information systems (GIS) are used to "store, manipulate, analyze, and output map-based, or spatial, information" (Steinberg & Steinberg, 2015). For the first three decades in the evolution of GIS, 3D was largely a niche field that operated outside of the mainstream of desktop or web-based GIS. That has changed over the past decade, with 3D being an expected capability for visualization as well as analysis.

Game engines are now being used to simulate both real and imagined landscapes. GIS and video game technology evolved largely independent of one another. The quality of 3D graphics and ability to model the environment in GIS lagged video game technology for years and is now just catching up (Shepherd & Bleasdale-Shepherd, 2011; Kirill, 2016). Recent years have seen advances in the ability of GIS-based 3D rendering software to export directly or indirectly to popular game engine software, including Unity and Unreal, resulting in a more fluid and realistic 3D experience of georeferenced landscapes. What was once a very custom niche in software development is becoming more mainstream as GIS and game engine developers are developing standardized tools and procedures for preparing terrain models for game engine applications (Dominika & Dariusz, 2016). Interestingly, there is a growing interest in the potential to leverage virtual reality games in collaborative 3D planning environments (Bishop, 2011).

Dioramas were previously described in terms of a physical setting integrating 2D (painting) and 3D (physical model) content, but they are not limited to tangible, material formats. The concept of a digital diorama has gained attention for educational purposes, including the ability to experience locations throughout the world through a virtual experience in both immersive and non-immersive settings. The digital diorama enables the creation of multiple narratives from a single-story database, including the ability to create multiple viewpoints, and potentially multiple interpretations from those viewpoints (Young, 2004). Virtual reality applications have allowed large audiences to experience ecological settings that would be dangerous or vulnerable if visited in person (Gross, 2017).

Although not an approach for generating landscape models, augmented reality (AR) has shown promise as a tool to educate and provide context for landscapes experienced in the real world (Bishop, 2015). As a supplemental tool, AR can help audiences gain additional context for place-based landscape planning issues.

Virtual geographic environments (VGE) extend the experience further through highly realistic immersive environments that provide engaging and memorable experiences (Coltekin, Lokka, & Zahner, 2016). It has been suggested that VGEs should be a useful interface since humans are accustomed to navigating in 3D space (Cartwright et al., 2001). However, there are issues with users becoming disoriented in VGEs, and the high information intensity can lead to information overload (Coltekin, Lokka, & Zahner, 2016). Navigation, for example, can occur over distances and speeds that do not reflect reality. The lack of visual detail in VGEs can also lead to users becoming lost in 3D space with VGEs. It is not yet clear what tasks these environments are well suited to address. In partial response to this need, You and Lin (2016) propose a research agenda for VGE technology and applications.

Overview of Visualization

Visualization and Visual Literacy

The visualization community has developed distinct specializations based on how the use of *space* is encoded in a given dataset (Munzner, 2015). In *scientific visualizations*, there is a specific spatial component inherent within the dataset – it can be mapped to a geometric shape or a mathematically defined coordinate system (Barruos, 2014). As a subset of scientific visualization, *geographic visualization* more specifically defines that space in connection with earth science data, including terrain, topography, or bathymetry. For purposes of this research, the term *landscape visualization* will be used since the phenomena being investigated are represented by specific human or natural features of the landscape.

Conversely, applications of *information visualization* leave the decision to leverage space to the designer. Information visualization may combine aspects of traditional graphics, imaging, and human-computer interaction (Gershon & Page, 2001). Both scientific visualizations and information visualizations can be static, animated, or dynamic (Lovett, Appleton, Warren-Kretzschmar, & Von Haaren, 2015).

Aside from the treatment of space, the distinction between scientific (including geographic or landscape) visualization and information visualization is significant in terms of the treatment of the third dimension. In general, the scientific visualization community recognizes the importance of 3D and supports its use where appropriate, mainly when adding the third dimension helps the user to see phenomena that would otherwise be invisible to or occluded from view (Coltekin, Lokka, & Zahner, 2016). However, 3D is rarely useful in information visualization applications. It tends to add ornamentation at the expense of clarity and is considered by some to be “chart junk” (Tufte, 1983).

In the context of landscape visualization or computer graphics in general, the term “3D” requires some additional clarification. In digital applications, 3D usually refers to 2.5D, in that 3D graphics are projected onto a 2D screen. The third dimension is simulated by leveraging a variety of depth cues that rely on both pictorial and physiological perception. “True” 3D, such as would be encountered in physical 3D models, is rarely represented in landscape visualizations (Knust & Buchroithner, 2014), although immersive experiences attempt to approximate that experience.

Geovisualization and the “Map Cube”. Alan MacEachren’s visualization cube (MacEachren, Bishop, Dykes, Dorling, & Gatrell, 1994) provides a useful framework to situate various approaches to landscape visualization (see Figure 9). The cube considers visualization along three axes: public versus private, revealing unknowns versus presenting knowns, and the degree of interactivity.

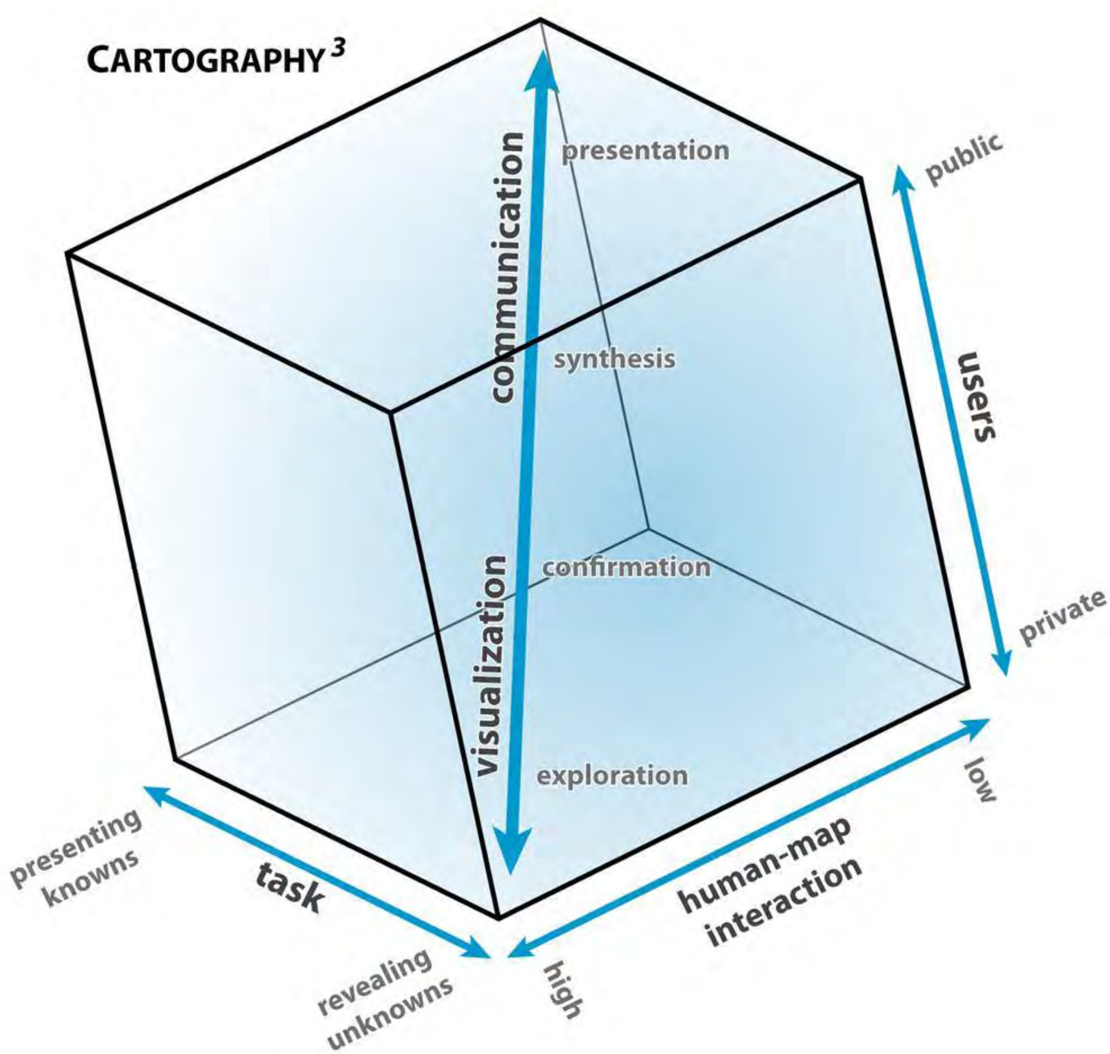


Figure 9. Geovisualization or map cube. (Image Credit: Field (2018) based on MacEachren, Bishop, Dykes, Dorling, & Gatrell, 1994).

MacEachren considers geographic visualization more narrowly and suggests that it is appropriately situated in the exploratory corner of the cube that describes a map user in the private, exploratory, and high interaction realms. Conversely, cartographic communication is in the explanatory corner of the cube, where the message is known, generally static, and aimed at a public audience. The visualization cube is an effective way to emphasize that geographic visualization goes well beyond what would be considered the focus of traditional cartography, and establishes linkages to the fields of multimedia, virtual reality, and exploratory data analysis (Field, 2018). Although the distinctions associated with position inside the cube are useful for clarifying audience, intent, and functionality, for purposes of this research *landscape visualization* is considered in a broader context and a variety of individual or group settings.

In summary, interactive landscapes can be used to communicate known environmental issues, but they can also be investigated by the user to discover new knowledge. Landscapes can be used in a personal or private setting, or they can be used in public, participatory settings. Finally, landscapes can be presented (1) as static images, (2) as animations (where the creator of the visualization presets the viewing angle), (3) through interactive web scenes (enabling the user to control the viewing angle), or (4) through immersive experiences (where the user is positioned *within* the view).

Graphicacy and Visual Literacy

Balchin & Coleman (1966) proposed the term *graphicacy* as a counterpart to literacy (textual skills), articulacy (oral skills), and numeracy (numerical skills). The basic idea is that human intelligence and communication requires basic knowledge related to the visual-spatial realm and that this should be an essential aspect of learning. Field (2018) further refines the concept of graphicacy as “the ability to communicate graphically” and extends graphicacy to incorporate elements of graphic arts, geography, cartography, computer graphics, and photography (see Figure 10).

Graphicacy is related to the concept of *visual literacy*, which is concerned with the ability to derive meaning from information provided in graphical form. Trumbo (1999) describes visual literacy as a “holistic construct that includes visual thinking, visual learning, and visual communication”.

Visual literacy in science communication is receiving an increasing amount of attention (Trumbo, 2000; Trumbo, 2006), both from the perspective of visual learning capabilities of the end user and visual communication skills of the scientist. Correspondingly, landscape visualization draws upon the interpretive and communicative skills of the scientist and the end user’s ability to discern meaning from the visualization. For the creators of scientific and landscape visualizations, it is vitally important to understand how images of scientific topics communicate (or fail to do so) (Trumbo, 2000).

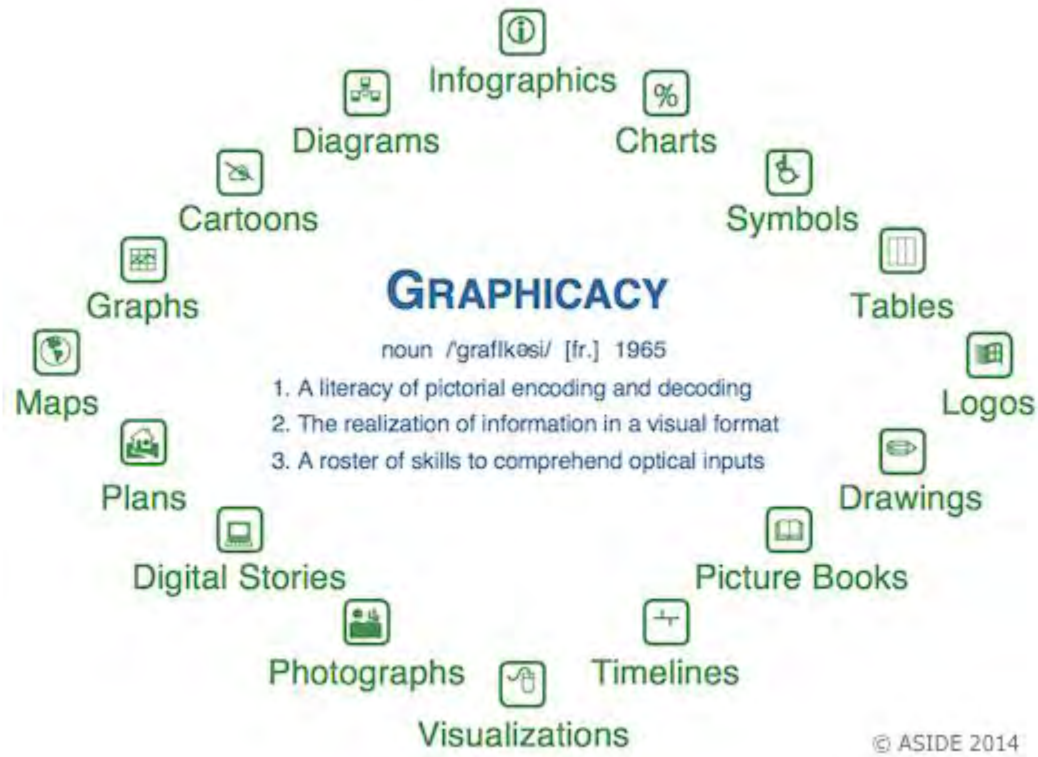


Figure 10. Forms of graphicacy. (Image Credit: Aside blog, accessed April 2, 2019, from https://visual.ly/community/infographic/education/graphicacy)

Alberto Cairo (2013) has developed a visualization wheel that illustrates challenges in science communication strategies, mainly where visualization designers and their audiences are comprised of participants of varied backgrounds. Developed initially as a way of representing the challenges in infographic design, Cairo's wheel illustrates the different tendencies of (1) scientists and engineers versus (2) artists, graphic designers, and journalists in terms of how well various graphic elements resonate.

The preferences articulated along the axes of the visualization wheel (see Figure 11) are fundamental to how landscapes are perceived and communicated in cartographic representations. For example, place-based 3D rendering of landscape features is likely to emphasize (1) decoration over functionality, (2) originality over familiarity, (3) lightness of content over density, and (4) figuration over abstraction.

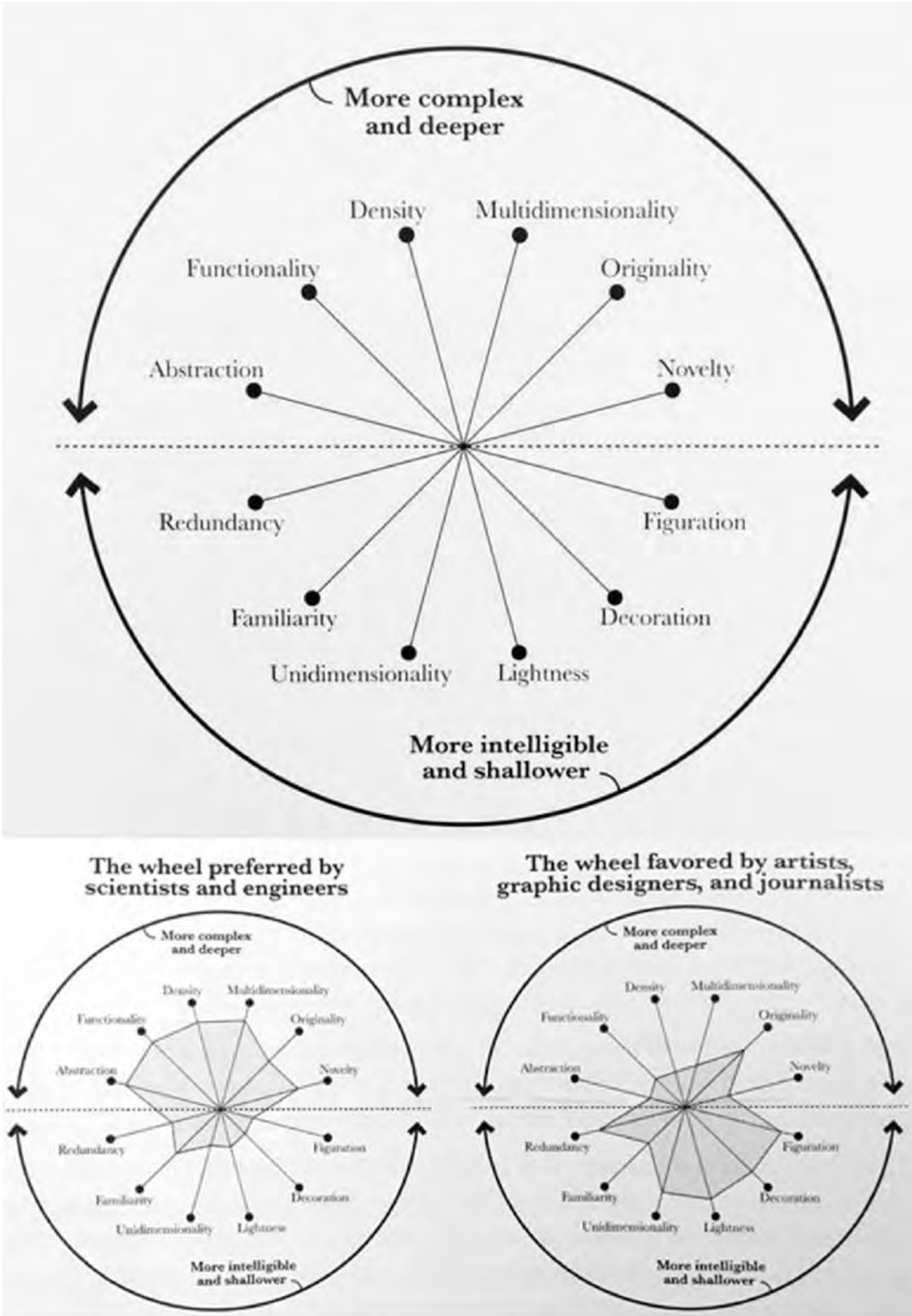


Figure 11. Visualization wheel for infographics. (Image credit: Cairo, A. (2012). The Functional Art: An introduction to information graphics and visualization. New Riders, reprinted with permission of the author).

Cognition Issues

Cognitive science underlies geographic visualization. In fact, over the past two decades, there has been substantial research in the fields of human factors of geovisualization, navigation systems, cognitive geo-ontologies, spatial thinking and memory, and cognitive aspects of geographic education (Montello, 2009). What these human factors have in common is their role in influencing a visualization system's usefulness, and therefore should impact the design and evaluation of visualization tools (Tory & Moller, 2004). An overarching goal of any visualization should be to maximize the cognitive productivity of end users (Ware, 2013), given that memory and attention are finite resources and humans generally are unable to store much information in internal visual working memory (Munzner, 2015).

Visualizing the third dimension. Visualization in 3D presents both challenges and (potential) advantages. In landscape visualization, adding the third dimension implies that the viewpoint ("camera position") and the viewing angle can change. By adjusting the viewpoint away from a 2D *planar* (overhead) parallel projection, a *perspective* view (often referred to as a "birds-eye" view) is obtained. A perspective view approximates characteristics of human vision, and as such can be a good choice for representing landscapes or terrain (Field, 2018). A *profile* view is obtained when the camera is aligned with the Earth's surface. Profile views are familiar to humans given that we experience the world from the earth's surface (Patterson, 1999).

Perspective views are common to 3D maps in general. They are associated with a more realistic and user-friendly representation of the height dimension as opposed to techniques for showing elevation on a 2D surface (Petrovic, 2003). However, greater flexibility in viewing direction can lead to poor representations that can, in turn, lead to additional cognitive load on the end user (Neuville, Poux, Hallot, & Billen, 2016). Also, perspective views can lead to occlusion, where portions of the landscape are hidden from view (Zhang, Zhang, & Xu, 2016). Relatedly, increasing the dimensionality from 2D to 3D can lead to reduced accuracy of perception and corresponding difficulties associated with estimating volumetric measurements of features due to occlusion (Field, 2018).

Also, using 3D maps or visualizations for instruction or problem solving may be particularly problematic as they may require additional training to interpret (Savage, 2006).

The use of the third dimension in visualization is usually warranted when the user's task requires them to have some fundamental understanding of 3D features or scenes that exist in the real world (Munzner, 2015). There is considerable evidence that 3D can be better than 2D when the task requires an understanding of shape characteristics (St. John, Cowen, Smallman, & Oonk, 2001). However, the use of 3D in all other contexts should be carefully considered, as distance judgments are inaccurate, features can unnecessarily collude, and perspective can lead to distortions that may not be immediately recognizable (Munzner, 2015). For example, 3D would not be a good approach if the task is to extract values of latitude or longitude since the scale of a 3D view is variable across the map or scene (Savage, 2006).

Interestingly, some users have indicated a preference for 3D to accomplish specific tasks, but ultimately performed better using 2D visualizations (Andre & Wickens, 1995). Huk (2006) suggested that "high-spatial" people may perform better in using 3D in specific contexts, suggesting that it may not be appropriate to generalize these results across the broader population when evaluating performance. Finally, several studies have shown that a user's performance with 3D environments can be enhanced with additional exposure or training (i.e., it can be a *learned* behavior) (Green & Bavelier, 2007; Harrington, 2011; Sungur & Boduroglu, 2012).

Depth perception and applied cue theory. Two-dimensional image plane information is processed much more efficiently than depth information (Ware, 2008), and as a result we leverage a series of depth cues to help us understand the structure of objects in 3D space (Kraak, 1988; Wanger, Ferwerda, & Greenburg, 1992; LaViola, Jr., Kruijff, McMahan, Bowman, & Poupyrev, 2017). Different depth cue taxonomies have emerged over the past few decades (see MacEachren, 1995 for a map reading examples and Ware, 2013 for a more generic example), but they share the taxonomical distinction of physiological clues vs. pictorial clues. *Physiological* clues are associated with the nature of monocular or binocular eyesight and relate to characteristics of the biology and physical properties of vision (e.g., eye convergence, stereoscopic depth, retinal disparity).

Pictorial clues focus on "tricks" the scene creator can employ to give the appearance of depth on a 2D surface. Pictorial clues include the use of perspective views, gradient textures, size gradients, the position of objects relative to one another, occlusion, shadows, and shading. Also, in interactive applications depth understanding can be enhanced using motion. *Motion parallax* is the phenomenon by which the apparent shape of objects changes as the viewpoint changes (MacEachren, 1995). Objects closer to the viewer move more quickly than those in the distance. Motion parallax can be used in animated "fly-throughs" to provide a broad, 3D perspective of landscapes (Lai, Lai, Kwong, & Mak, 2010).

Color is also used in landscape visualization as a depth cue. Artistic approaches to using color as a depth cue tend to focus on atmospheric effects that reduce the amount of contrast in areas further away from the viewer. Landscape painters use this effect by progressively reducing color pigments in the middle-ground and background.

Ultimately, the role of the designer is to select which depth cues to use in a particular context (Ware, 2013). In landscape visualization software applications, some of those decisions are made by default. In visualization, like cartography, caution should be exerted before accepting defaults (Jones, 2010).

Scene gist. Studies have shown that observers can very quickly grasp the content of a landscape from a single glance. This phenomenon, known as *scene gist*, pertains to information processing at multiple levels of complexity, ranging from low-level features such as object color to high-level information such as semantic knowledge (Oliva, 2005). Landscape visualization applications should consider the ramifications of scene gist because it has been demonstrated that the viewpoint of the observer can significantly affect the ability to rapidly characterize scene views (Loschky, Ringer, Ellis, & Hansen, 2015). In other words, the choice of birds-eye or perspective versus planar views of a landscape can greatly impact the retention of information by the observer.

Design issues. French cartographer Jacques Bertin first articulated the concept of visual variables (see Figure 12) in cartography in his classic work *Semiologie of Graphics* (Bertin, 2011). Virtually all graphic elements on a page can be represented by combinations of the variables of position, size, shape, color, orientation, and texture (Roth, 2017) which, used in conjunction with one another in a mapping context, creates a "visual grammar of maps" (Mark & Franck, 1996).

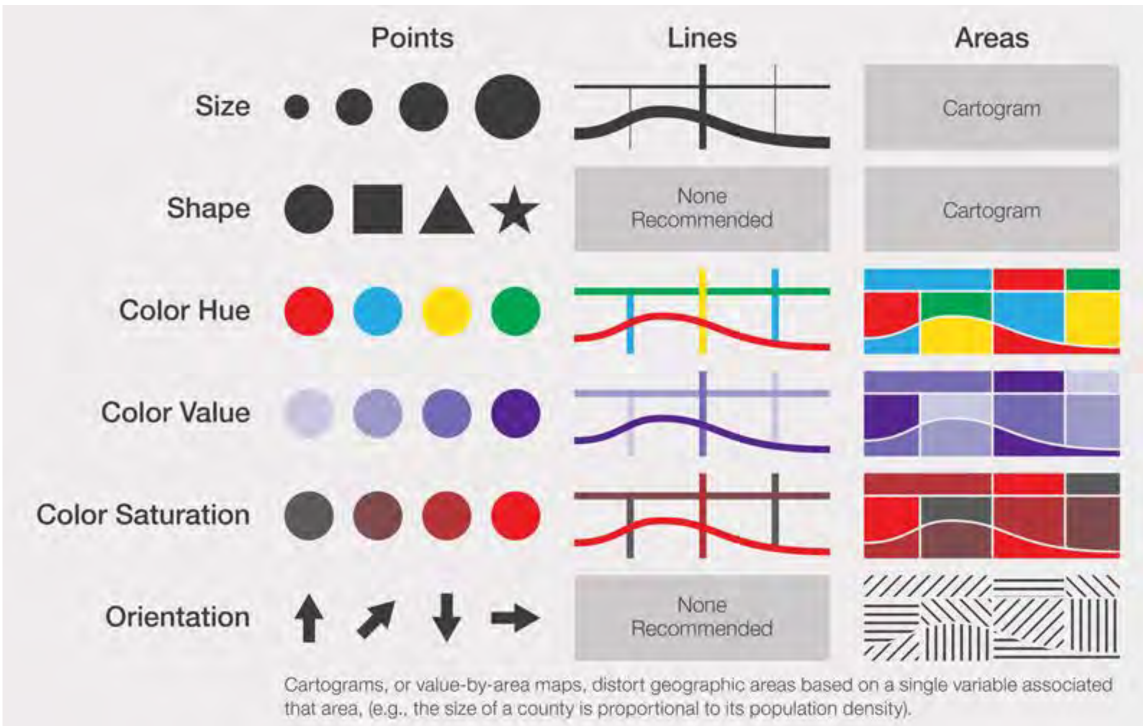


Figure 12. Cartographic visual variables. (Image credit: White, T. (2017). Symbolization and the Visual Variables. The Geographic Information Science & Technology Body of Knowledge (2nd Quarter 2017 Edition), John P. Wilson (ed.).DOI: [10.22224/gistbok/2017.2.3](https://doi.org/10.22224/gistbok/2017.2.3)). Reprinted with permission of the author.

As technology has evolved and additional cartographic options have been developed, additional visual variables have been proposed to incorporate 3D and animation. As will be discussed, for 3D visualizations the position of the camera and its viewing angle come into play. Specifically, position, orientation, and motion need to be considered not only from the perspective of objects in a scene, but also in terms of the camera or viewpoint (Coetzee, Schiewe, Çöltekin, & Rautenbach, 2015). Also, not all 2D visual variables work as well in interactive 3D scenes. Aside from color and texture, other visual variables can get lost in translation when moving from 2D to 3D (Rautenbach, Coetzee, & Schiewe, 2015). Animation requires additional dynamic visual variables, including scene duration, rate of change between scenes and scene order (DiBiase, MacEachren, Krygier, & Reeves, 1992).

Graphic design considerations. Frankel & DePace (2012) suggest that there are three primary purposes associated with scientific graphics. Each of these can apply to landscape visualizations. One objective would be to illustrate the *form and structure* of the landscape, including representations of terrain, buildings, and vegetation. Secondly, scientific graphics can be used to communicate *change over time*. Finally, they may also be constructed to encourage the user to *compare and contrast* views and the elements they comprise. Given these overarching purposes, graphic design techniques can enhance the user's understanding of landscape phenomena.

All maps (and geographic visualizations) are abstractions of reality (Field, 2018). Furthermore, "completeness" is likely not the objective in visualization or mapping, so the choice of features to include is a deliberate one. Realism may or may not be the ultimate goal of landscape visualization. Lange (2011) suggests that landscape visualizations are illusions of past, present, and future conditions, and the production of truly "realistic" landscape in past and future applications may be counterproductive. However, if human recognition of specific visualization elements is important then striving for photorealism may be necessary (Borkin et al., 2013). From an application perspective, realism has been shown to enhance trust among different categories of stakeholders, presumably because they have a common visual understanding of design decisions and their impacts (Julin et al., 2018). Appleton & Lovett (2003) found that the importance of realism in landscape visualization is context dependent and that realism associated with some elements or objects in a scene are more important than others.

In terms of traditional map use, Dong & Liao (2016) found that users interacting with 3D maps were less effective and less efficient for standard map reading tasks since the 3D representations required a higher cognitive workload. They did, however, find that users performed better with 3D maps when the task at hand required self-localization or orientation *within* a view as opposed to a map.

Color. Color is one of the most important visual variables in landscape communication. Aside from practical, well-known choices such as associating green with vegetation and blue with water (Jones, 2010), color design decisions are often dependent on the project's purpose (Ervin & Hasbrouck, 2001). Tufte (1990) proposes that a grand color choice strategy in visualization, in general, is to select colors found in nature -- notably lighter shades such as blues, yellows, and greys. This would seem obvious in landscape visualization, but the purpose of a particular scene may suggest deviating from that rule of thumb. In digital applications, colors are typically represented in terms of Red-Green-Blue (RGB) values. Since plants come in many different shades, slight variations in red or blue can add substantial variety to vegetation by altering the shades of green (Ervin & Hasbrouck, 2001). Another consideration is the choice of base maps that underlie 3D features. A preferred approach would be to select muted or even semi-transparent hues that provide context but do not overwhelm the objects to be emphasized in the scene.

Related to colors are choices of textures. Textures can be used to represent visually complex features by adjusting the size or density of elements within a given texture pattern (Ware, 2013). Variations in texture density can also be used to enhance depth perception.

Gestalt principles. Gestalt principles are concerned with how the mind interprets various patterns of elements as groups. Of relevance to 3D landscape visualization, important Gestalt principles consider the configuration of elements in a view based on their proximity and similarity (MacEachren, 1995). Leveraging Gestalt principles can result in less demand on cognitive resources. Related to both Gestalt principles and cue theory, figure-ground relationships factor into design decisions to communicate which objects should appear in the foreground as opposed to the background (Ware, 2013).

Cartographic design considerations. Design principles and guidelines for 3D maps are a relatively recent development. Haeberling (2004) proposed a series or principles that could be applied based on different stages of the design process, including the modeling, symbolization, and visualizations phases (Terribilini, 2001 – see Figure 13). The specific principles for 3D maps that differ from 2D maps relate to (1) data abstraction, (2) dimensional representation, and (3) camera, (4) lighting and (5) atmospheric effects. Haeberling's work has served as an invitation for further research on 3D cartographic principles, many of which have direct utility in the design of interactive 3D landscape visualizations.

Patterson (1999) provided additional guidance on designing manual representations of 3D landscapes on 2D maps, including best practices for showing the horizon, illumination considerations including the source/direction and color of light, atmospheric effects such as haze and shadow, tradeoffs between perspective and how to use foreshortening to gradually flatten the landscape deeper into a scene until it merges with the horizon. Many of these techniques have now been built into landscape visualization software packages.

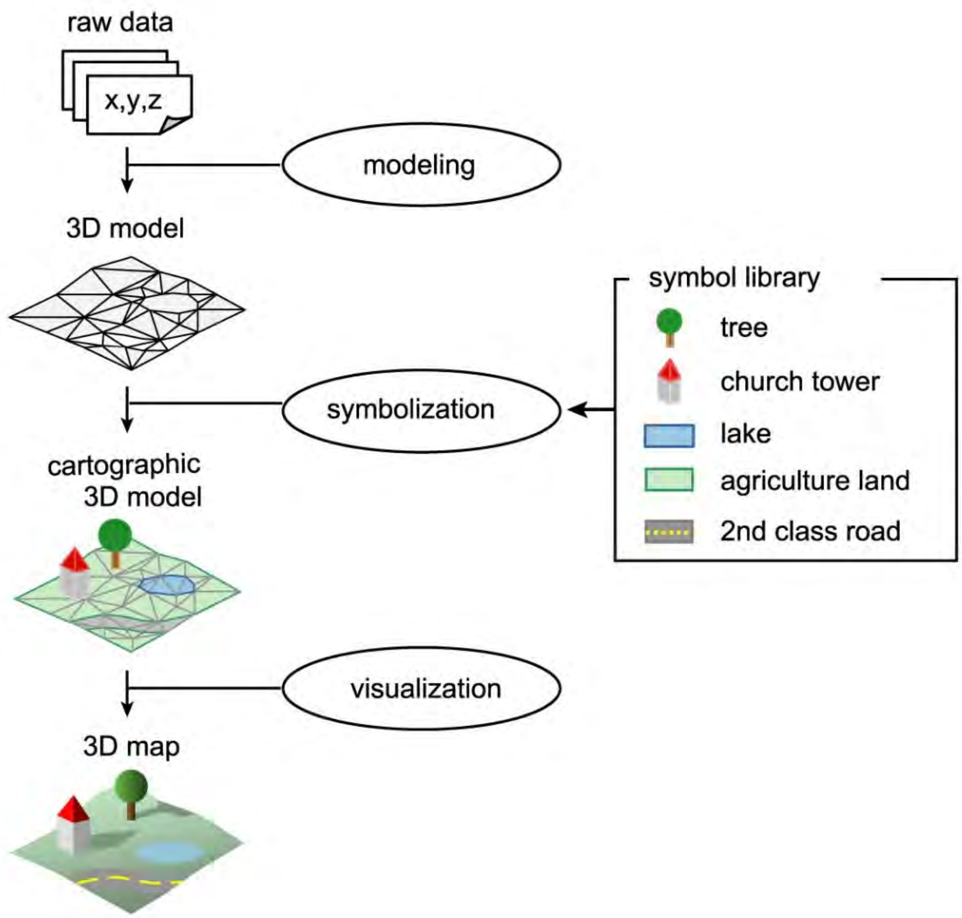


Figure 13. Schematic design process for 3D maps (Image credit: Haeberling, C. (2004). Cartographic Design Principles for 3D Maps - A Contribution to Cartographic Theory. *22nd International Cartographic Conference*, 14**,** modified from Terribilini, 2001). Reprinted with permission of the author.

Extending beyond the 3D map itself, map labels are a particular challenge in interactive landscape visualizations. The preferred approach is to separate any map surface representations from the corresponding text or label components. This prevents the text from becoming distorted with changes in perspective. Map labels can then be added as a separate layer that conforms to the depth cues established by the cartographer/designer, enabling the typographic components to respond to changes in the viewing angle or the rotation of the view (Field, 2018).

Interaction design considerations. Interaction design extends beyond constructing the visual aspects of the landscape and incorporates considerations of the end user's behaviors when confronted with the application itself. In modern web mapping and data visualization applications, there are a variety of possible interactions, including panning and zooming, clicking on, or hovering over a feature to reveal additional information, animation, and brushing linked maps, graphs, and textual elements, to name a few (Field, 2018). For 3D applications, other forms of interaction are possible, including tilting the view, changing the camera angle/viewpoint, and rotating the camera within the scene.

Ben Shneiderman's (1996) visualization mantra recommends "overview first, zoom and filter, and details on demand" as an organizing principle for designing visualization applications. This framework is now commonly used in 2D web mapping applications and can be used in 3D landscape visualizations as well.

Roth (2017) has proposed a systematic approach to considering map interaction by looking at a series of stages in map use, including: "(1) forming the goal, (2) forming the intention, (3) specifying an action, (4) executing the action, (5) perceiving the system state, (6) interpreting the system state, and (7) evaluating the outcome".

Earlier (2012), Roth surveyed the literature to differentiate the specific forms of cartographic interaction primitives that have been used in task taxonomies. He defined a cartographic interaction primitive as "a basic unit of interactivity that is combined with other primitives in sequence when using interactive maps" (Roth 2017). There have been many variations and attempts at cartographic interaction taxonomies that apply to map reading and geovisualization interaction (See Andrienko, Andrienko and Gatalsky 2003, Andrienko & Andrienko 2006, Blok et al 1999, Casner 1991, Crampton 2002, Knapp 1994, MacEachren et al 1999, Wehrend 1993, Yi et al 2007, and Zhou & Feiner 1998). These go well beyond the scope of this research, but many of these taxonomies share similar task-based objectives. These include:

- Identify
- Locate
- Compare
- Distinguish
- Categorize

- Cluster
- Rank
- Associate
- Correlate

Other interaction primitives that appear less frequently in the literature include generalize, reveal, switch, encode, and extract/suppress, among others.

Interaction supports exploration, insight, and visual thinking (Field, 2018). A systematic evaluation of human-computer interaction principles is key to ensuring that a landscape visualization will address the needs of its intended users.

Research Implications of 3D Visualization

Research involving interactive 3D scenes can present unique challenges. Some of these challenges are associated with the exploratory versus explanatory nature of *tasks* in different settings. From the visualization designer's perspective, the tasks undertaken by the end users are just as important as the kind of data being visualized (Munzner, 2015). Three-dimensional landscape visualization software can be used to create artistic and creative designs. Without careful attention to the user's needs, skills and perception, the result may be to miss the mark of the visualization, which is typically to *communicate* some form of geographic information (Pegg, 2012) as opposed to creating a pretty graphic.

Success in task accomplishment is typically based on measures of usability (including efficiency and effectiveness), and these can be difficult to gage in exploratory applications common to landscape visualizations (Bleisch, 2012). Conversely, research involving 2D maps has traditionally focused on specific map reading tasks associated with navigation and measurement. Clearly defined questions articulated through specific tasks can be more easily measured and more directly used to test hypotheses (Board, 1978). With respect to landscape visualizations in particular, tasks that require a broader visual processing/scene interpretation are more likely to benefit from 3D visualization whereas tasks that require local visual information processing may be complicated by 3D (Coltekin, Lokka, & Zahner, 2016; Getzner, Färber, & Yamu, 2016). Furthermore, it is essential to make sure that the study design is measuring what is intended ("Gulf of Evaluation"). Several early studies that presumably concluded that 3D has certain benefits have since been refuted or superseded based on an acknowledgment that the original study design was inadequate (Munzner, 2015).

Finally, research methods that involve interactive or dynamic displays (whether 2D or 3D) can present additional challenges, as the user's view is constantly changing based on incremental decisions being made along the way (Ooms et al., 2015).

Landscape Modeling Techniques

As one of the first application areas of computer-aided landscape planning and design, landscape modeling grew out of some of the earliest work in GIS at Harvard's Graduate School of Design in the 1960s and 1970s. Early efforts focused on some of the unique challenges associated with modeling and rendering landforms as well as associated vegetation, buildings, and water features (Ervin & Hasbrouck, 2001).

As was noted earlier in this chapter, all maps and landscape visualizations are abstractions of reality. In mapmaking, this is related to the concept of cartographic generalization (Munzner, 2015), where the cartographer or the creator of the visualization is making conscious (or unconscious) choices about what features to show based on tasks anticipated for the user. For digital maps and landscape visualization, rendered features are based on data stored in a computer that is then symbolized (using visual variables) to represent categories or amounts of information. Data information models are now commonly used to store that information in a logical structure. For example, the ESRI City Information Model (Reitz & Schubiger, 2014) stores data by themes, including the built environment, the legal environment, and the natural environment. Within each of these themes, a wide variety of item types are stored.

This thematic approach to characterizing landscape structure typically separates landscape elements into three components: cultural (or built) elements, vegetation, and terrain (see Figure 14). These categories are typically modeled differently and draw upon distinct data sources.

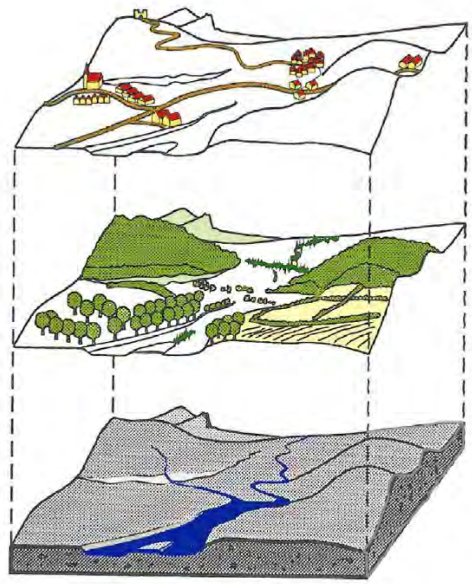


Figure 14. Three main structural layers of a landscape - cultural, vegetation, and biophysical (terrain). (Image credit: Walz, U., Hoechstetter, S., Drăguţ, L., & Blaschke, T. (2016). Integrating time and the third spatial dimension in landscape structure analysis. *Landscape Research*, *41*(3), 279–293. https://doi.org/10.1080/01426397.2015.1078455).

Procedural modeling involves the generation of landscape features based on a set of rules from a fixed set of parameters (Ganster, 2012; Schinko, Krispel, Ullrich, & Fellner, 2015). Advances in computer processing speeds and graphics rendering capabilities have led to increased use of procedural modeling approaches (Fletcher, Yong Yue, & Al Kader, 2010). There are typically computer scripts that specify procedures that result in automatic content creation. Benefits of procedural modeling include data compression and the ability to generate content over large areas without human intervention (Smelik, Tutenel, Bidarra, & Benes, 2014). Procedurally generated landscapes are now used in video games, movies, and other simulations.

Procedural Modeling

Procedural modeling can be used to generate structures, vegetation, roads, and water effects. The benefits to procedural modeling of landscapes are associated with the economies of scale of automated vs. "manual" modeling techniques (Figure 15). Landscape object libraries and tools have been developed to help with the automated generation and rendering of content (Sharma, Pettit, Bishop, Chan, & Sheth, 2011), including rules for vegetation and natural landscape features (Onrust, Bidarra, Rooseboom, & van de Koppel, 2015; Onrust, Bidarra, Rooseboom, & van de Koppel, 2017), roads and urban features (Lyu, Han, & de Vries, 2017), or combinations of natural and human landscape attributes (Grêt-Regamey, Celio, Klein, & Wissen Hayek, 2013).

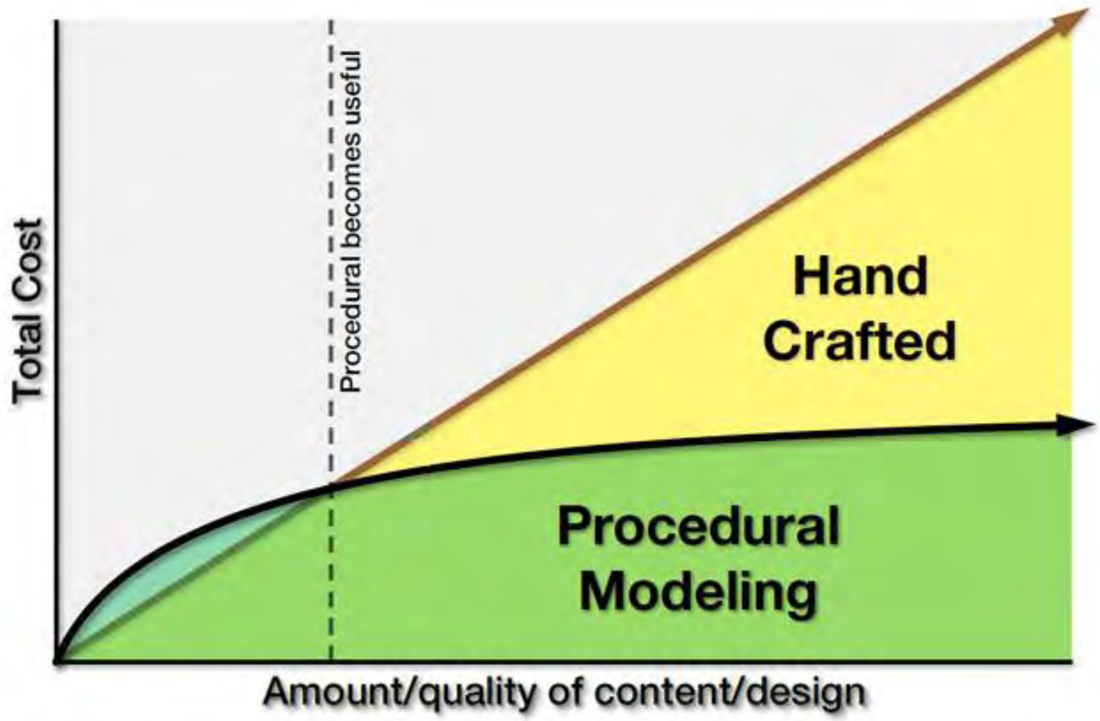


Figure 15. Procedural modeling provides benefits due to economies of scale resulting from automated, rule-based modeling. (Image credit: ESRI R&D Zurich, 2018)

Computer terrain modeling is a mature field in and of itself. Sophisticated algorithms have been developed to portray terrain in both two- and three-dimensional space. In general, these involve representing the surface of the earth based on digital elevation models (DEM), which in turn are generated from sample elevations collected at specific points (Field, 2018).

Increasingly, elevation data is collected from LiDAR (Light Detection and Ranging data). LiDAR is a remote sensing technology that uses light to measure distance at high spatial resolutions. LiDAR generates exact landform/terrain elevation data

(DEMs) as well as elevations of features that reside on top of the landscape. The elevation of terrain plus surface features such as buildings and trees are the basis for a digital surface model (DSM see Figure 16). The difference between DEM and DSM elevation in any given location can be used to approximate the height of a variety of landscape features as well as insights into *changes* in the surface over time (Mitasova, Harmon, Weaver, Lyons, & Overton, 2012).

Figure 16. Elevation surface represented through a (1) digital elevation model (DEM) and (2) digital surface model (DSM) (Image credit - Brown & Harder, 2016).

Buildings are typically rendered in 3D based on a vertical extrusion of a 2D building footprint. Further refinement of the rendered buildings implies attention to varying *levels of detail.* The concept of levels of detail relates to the complexity of geometry rendered in 3D computer graphics (Luebke et al., 2003). Varying levels of detail can be used in conjunction with foreground, middle ground, and background to speed up rendering where detailed landforms and features are not necessary (Ervin & Hasbrouck, 2001). Decisions regarding what level of detail is appropriate are project specific and dependent on the purpose of the individual project (Barbarash, 2008).

Procedurally generated vegetation can be rendered based on imagery draped on terrain, through textures applied to the terrain surface, or through the generation of solid representations, including simple parametric models or more complex 3D models generated from plant modeling software (Ervin & Hasbrouck, 2001). Water can also be rendered based on procedural rules, although it can be problematic due to water's inherent characteristics of transparency, reflectivity, and combinations of color. Finally, lighting, shadows, and atmospheric effects can add to the realism of a scene, when that is a goal of the designer.

Procedural modeling has advanced considerably over the past few decades, but it is not without issues. Challenges remain due to software-specific algorithms, lack of integration of different procedural methods (i.e., terrain vs. vegetation vs. structures), and lack of control/editing of automated output (Smelik, Tutenel, Bidarra, & Benes, 2014).

Web-based Landscape Visualization

Landscape modeling and visualization techniques discussed thus far are generally associated with desktop computer tools and methods. Although it has been demonstrated that 2.5D content is optimized for web-based streaming of 3D city models (Liang et al., 2016), creating interactive 3D visualizations for the web adds additional complexity and usability concerns. Many environmental and urban planning applications now *require* access to the visualization via the internet (Ki, 2013; Yang, 2016).

The disruptive arrival of Google Earth and Google Maps led to the proliferation of online mapping tools in the mid-2000s. Online 3D mapping and visualization have lagged somewhat due to algorithmic complexity and less intuitive navigation. In addition to navigation issues, the web-based 3D applications that exist are heterogeneous in the way that they handle content and the cartographic quality of that content (Sieber, Hollenstein, & Eichenberger, 2012). It has been recommended that additional research should focus on online 3D interaction and visualization among various user groups and for different applications.

Web-based static, animated and interactive maps and visualizations serve different purposes and vary in their effectiveness at achieving success for different types of tasks. Static maps are most familiar to use and usually result in the fastest response but can result in a higher error rate in task success (Herman & Stachoň, 2016) and provide minimal opportunities for exploration. For comparing two maps (in split-screen mode), Cinnamon et al. (2009) found interactive maps particularly useful. Similarly, van Schaik (2010) found that interactive 3D visualization was particularly effective in evaluating options in proposed redevelopment projects in public planning process settings.

Evaluative (Research) Methods

Steinberg, & Steinberg (2015) distinguish among three types of research that leverage GIS. These can be further interpreted in the context of landscape visualization research. In *descriptive* research, the goal is to observe and catalog data related to how a visualization is used. For *exploratory* research, the focus is on understanding behavior so that additional questions or hypotheses can be proposed. Finally, in *explanatory* research, there is a deliberate attempt to understand the relationship among variables and why a user behaves in a certain way. It is important to understand among these goals before determining the suitability of specific research methods.

The effectiveness of landscape visualization applications is inherently connected with the context in which they are used. Lovett, Appleton, Warren-Kretzschmar, & Von Haaren (2015) conducted a literature survey and drew from professional opinion to develop a series of criteria for selecting appropriate research methods. In general terms, they offered guidance on "when" landscape visualizations are appropriate, "what" to include, and "how" they should be displayed (see Figure 17). They considered the use of landscape visualization as a tool to communicate with stakeholders and proposed criteria associated with credibility, saliency, and legitimacy of a visualization relative to the needs of the audience. Jones, Haklay, Griffiths, & Vaughan (2009) proposed a minimalistic design approach to landscape visualization that is then measured relative to the *usability* criteria of efficiency, effectiveness, and learnability. Again, the emphasis is on the degree to which the visualization met the needs of the stakeholder group (in this case a multidisciplinary planning team). These (or similar) criteria are often used in visualization research. For *web* research of interactive tools, usability engineering criteria can provide quantitative and qualitative metrics that are well suited for data analysis (Haklay, Skarlatidou, & Tobon, 2010; Wang, 2014).

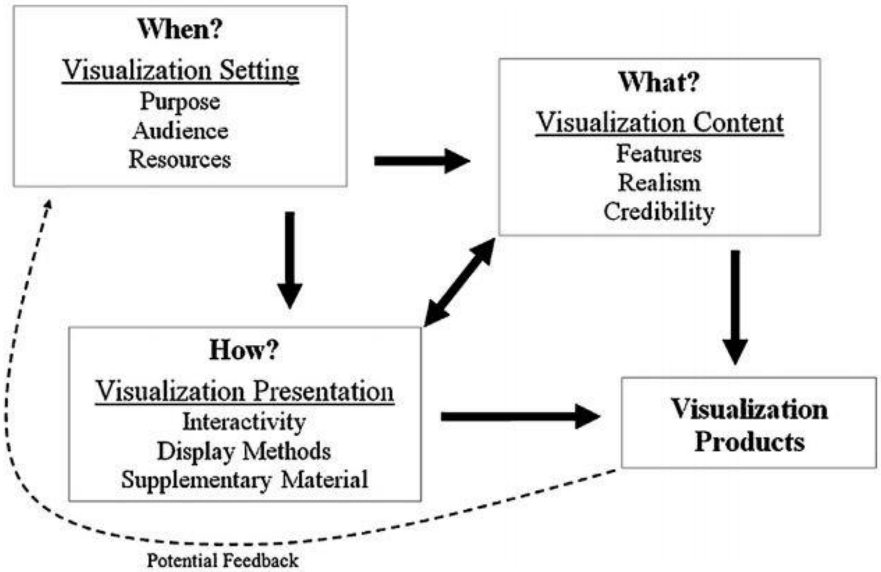


Figure 17. Questions to consider regarding the development and use of landscape visualizations (from Lovett, A., Appleton, K., Warren-Kretzschmar, B., & Von Haaren, C. (2015). Using 3D visualization methods in landscape planning: An evaluation of options and practical issues. Landscape and Urban Planning, 142, 85-94.) Reprinted with permission of the author.

The following sections describe frameworks, methods, and data collection techniques for landscape visualization research. It is not intended to represent a comprehensive discussion of research techniques in human-computer interaction, but rather focus on approaches commonly used in landscape visualization research.

Evaluation Frameworks for Landscape Visualization Research

Marsh & Haklay (2010) describe experimental frameworks as "structures in which methods and techniques are placed to yield the appropriate data". The framework of a research problem is essential to consider ensuring that the data collected will be the most appropriate for the research question under consideration. Frameworks used in landscape visualization research have included (1) formative evaluation, (2) comparative evaluation of two or more research configurations, (3) longitudinal studies, (4) convergent or multiple methods, (5) case studies, (6) remote studies, and (7) participatory design.

Formative evaluations. Formative evaluations are commonly used in software design since they often involve iterative development based on observations of a user.

They are also frequently costly in terms of time requirements necessary to assess evidence over several research stages.

Comparative evaluations. Comparative evaluations are useful when considering whether two or more approaches or scenarios are statistically different from one another. In landscape visualization research this could involve “before” and “after” visualizations for a given landscape or whether two different landscapes result in different user reactions.

Longitudinal studies. Longitudinal studies consider a single landscape visualization research question over a more extended time period. In these studies, it may be possible to observe patterns in learning, but they may be costly to conduct and are typically more complex in terms of analyzing data (Marsh, 2007).

Case studies. Case studies involve evaluating examples with the goal to generalize findings across a broader population. Case studies are common i*n exploratory* landscape visualization research, where the intent may be to transfer ideas for a particular place and scenario to other similar places (Steinberg & Steinberg, 2015). They can be time-consuming to conduct, and their proposed aim (generalizability) can also be their biggest challenge.

Remote studies. Remote studies are common with landscape visualization research, in that they are relatively inexpensive to conduct and that results from many participants can be collected quickly. However, the nuances of interactivity can be challenging to observe and quantify with remote studies, and it is difficult to control for the specifics of test settings.

Participatory studies. Participatory studies leverage pre-existing stakeholder groups to collect information in group settings. An advantage of participatory group research is that it may mimic actual planning scenarios and can be used at multiple stages in a planning process. Challenges with participatory studies include increased costs associated with orchestrating the test settings (Haklay, 2010) and controlling for the impacts of group dynamics on research results.

Mixed or convergent methods. Mixed or convergent methods (including both quantitative and qualitative methods) can be particularly useful for deriving conclusions when the combination of methods reinforce one another. Coltekin (2015) proposed that, in scientific research involving visualization, the *combination* of controlled research studies and additional qualitative methods may be most useful. Multiple methods also provide for a broader perspective, a greater number of variables, and complementary measures for the same concept (Cresswell & Clark, 2007). However, there is always the possibility that different methods may yield different or contradictory results because of the varying strengths and weaknesses of the methods selected.

Spatial ethnography. Spatial ethnography is a mixed methods approach that may be promising for landscape visualization research. It combines elements of spatial analysis along with the role visual conventions play in place-based settings (Kawano, Munaim, Goto, Shobugawa, & Naito, 2016). The spatial ethnography conceptual model may be particularly relevant when evaluating the perspective of local stakeholders in landscape visualization applications (Steinberg & Steinberg, 2015). As with other ethnographic approaches, the fieldwork or data collection involved may be time-consuming and demanding (Banks, 2018).

Grounded visualization. Somewhat related to spatial ethnography, *grounded visualization* combines elements of grounded theory (which focuses on collection and categorization of data before proposing hypotheses) and the exploratory nature of GIS-based landscape visualization (Knigge & Cope, 2006). In addition to the exploratory commonalities of grounded theory and landscape visualization, both approaches are also frequently (1) iterative and (2) combine the "particular" and the "general" (e.g., multi-scale) in their investigations. Given the potential for different impressions of landscapes among different stakeholder groups, grounded visualization may show promise as an organizing framework for landscape visualization research.

Research Methods and Data Collection Techniques for Landscape Visualization

Research methods involve specific techniques for collecting and analyzing data and information. They can leverage existing published work (e.g., literature reviews) or involve the collection of new data, take place in person or remotely, be synchronous or asynchronous, and involve individual or group processes.

Controlled experiments. Controlled experiments (including usability testing) provide quantitative measures of a user interacting with a landscape visualization. Typically measured in terms of success rates/errors and time to completion, experiments are widely used to assess how users interact with existing or proposed landscape visualization scenarios (Marsh, 2007). However, the highly structured experimental design may limit the transferability of study findings to real-world contexts (i.e., low ecological validity), and the exploratory nature of many landscape visualizations may limit options for measuring success for specific quantitative tasks.

Contextual inquiry. Contextual inquiry combines elements of interviews along with observations of a user completing a series of tasks. In landscape visualization development, contextual inquiry has been useful to develop scenarios that were then supplemented with actual observational data to develop and evolve prototypes (Lloyd & Dykes, 2011). This approach has also been used in evaluating interfaces in data visualization contexts (Shneiderman & Plaisant, 2009).

Questionnaires. Questionnaires can be a cost-effective way to gather information since once the instrument is developed, it can be widely distributed with little effort. Questionnaires can lead to an abundance of data to code and analyze, and there is less control over the setting in which the data is collected (Cairns & Cox, 2008). Czepkiewicz, Jankowski, & Młodkowski (2017) also note that online recruitment to complete questionnaires can result in biases towards younger populations, particularly where social media is used as a mechanism to engage participants.

Interviews and focus groups. Interviews and focus groups involve in-person data collection, with interviews typically one-on-one and focus groups usually involving a single moderator along with a group of participants.

Eye-tracking. Eye-tracking has been used to evaluate how users address map tasks and to a lesser extent visualization (Potocka, 2013; Dupont, Antrop, & Van Eetvelde, 2014; Pihel, Ode Sang, Hagerhall, & Nyström, 2015; Popelka, 2018).

Challenges associated with eye-tracking are that (1) it can generate a lot of data (Cairns & Cox, 2008) and (2) in the case of interactive visualizations, the content associated with the user's gaze changes as a landscape scene is navigated. In the case of this challenge, Ooms et al. (2015) have suggested that eye-tracking be used in conjunction with user logging so that the actual fixation of the eye can be tracked and analyzed.

Audience of Landscape Visualizations

For purposes of landscape visualization research, there are different audiences engaged and these influence potential test settings (Figure 18). Environmental and landscape planning are frequently conducted in participatory settings that may combine multiple stakeholders representing various interests. As previously mentioned, this can be difficult to fully replicate in a test setting due to the challenges associated with participatory studies research design.

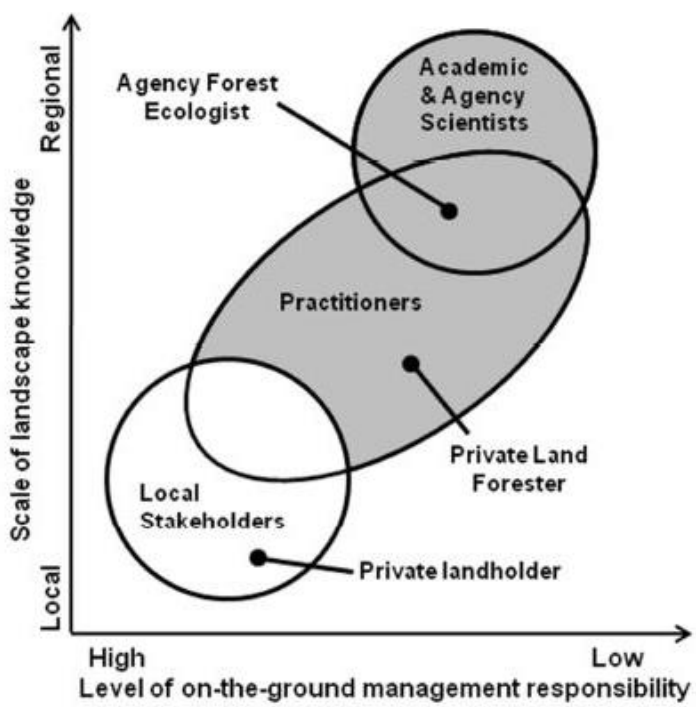


Figure 18. Conceptual diagram of different types of stakeholders in landscape visualization applications. (Image credit: Adapted from "A conceptual diagram of the different types of experts – local stakeholders, practitioners, and academic or agency scientists – who can provide input for scenario-building and

modeling approaches.” Price, J., Silbernagel, J., Miller, N., Swaty, R., White, M., & Nixon, K. (2012). Eliciting expert knowledge to inform landscape modeling of conservation scenarios. Ecological Modelling, 229, 76-87. Reprinted with permission of the author.

Existing studies have attempted to evaluate the (1) differences between laypersons and technical or subject matter experts (Herman, Řezník, Stachoň, & Russnák, 2018), (2) differences in age of participants and amount of experience with 3D game and interaction environments (Sjölinder, Höök, Nilsson, & Andersson, 2005), and (3) differences in roles relative to the problem being investigated (e.g., researcher vs. practitioner vs. local stakeholder) (Pettit, Raymond, Bryan, & Lewis, 2011). Wherever possible, attempts should be made to identify and involve the primary audience of the visualization, including those who will be using it to carry out their job (Markel, 2007), as well as secondary audiences, or those with an interest in the topic at hand but not directly impacted using the visualization. In general, it is preferable to involve a smaller group of intended users in tests than a larger group of inappropriate or irrelevant users (Marsh, 2007).

Task Definition

Once the audience is identified, specific attention needs to be given to the tasks a user would be expected to accomplish using the visualization. Tasks should emerge after a consideration of the overall communication challenge being addressed, the goal of the visualization, and the context in which it will be used (Frankel & DePace, 2012).

Various task taxonomies have been proposed, including Shneiderman’s general taxonomy for interface design (Shneiderman & Plaisant, 2009) and taxonomies specific to geovisualization (Koua, MacEachren, & Kraak, 2006). These taxonomies capture the categories of interaction a user would be expected to consider when exploring an interactive visualization.

Landscape Visualization Applications

McCandless (2014) proposes that all good visualizations share common traits related to information, story, goal, and visual form (Figure 19). Lacking one or more of these characteristics leads to an inferior product. The *information* realm is based on the integrity of the underlying data. *Story* deals with the "interestingness" of the visualization, ensuring that the concept is relevant and meaningful. *Goal* refers to the functional purpose of the visualization. Finally, the *visual form* implies that the appearance of features in the visualization are representative (or serve as a metaphor) of ideas. Each of these traits applies to landscape visualizations.

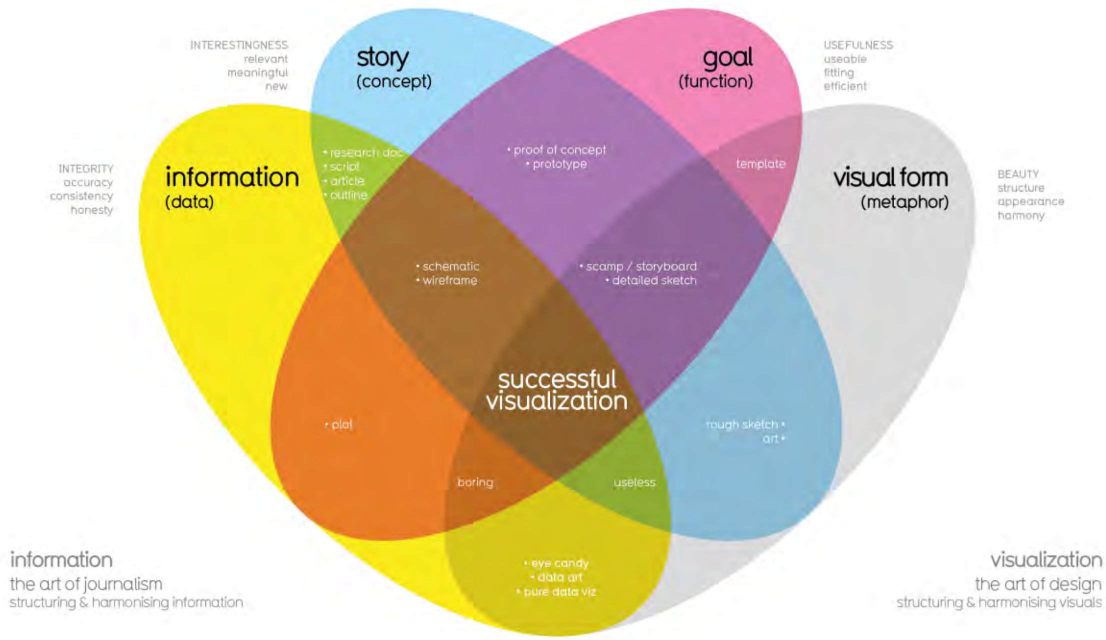


Figure 19. McCandless' elements of a good visualization (Image credit: "InformationIsBeautiful.net"). Reprinted with permission of the author.

Ethical Concerns in Landscape Visualization Applications

Sheppard applies similar traits of "good" visualization to arrive at a "Code of Ethics" for landscape visualization (Sheppard, 2001). His rationale is based on the recognition that there are not just cognitive principles at work with landscape visualizations, but also emotional and intuitive reactions. The full code of ethics is beyond the scope of this discussion but generally focuses on criteria associated with *disclosure*, *drama*, and *defensibility* (Sheppard, 2012). As previously described, landscape visualizations are abstractions of reality and therefore can introduce issues of uncertainty and bias. This is particularly pertinent when visualizing *proposed* projects and alternative futures or scenarios, where highly realistic scenes can result in misleading assumptions of authenticity (Sheppard, 2005; Sheppard & Cizek, 2009). As with McCandless's information/data integrity criteria, the ethics of landscape visualization require that an effort is made to ensure credibility and legitimacy (Lovett, Appleton, Warren-Kretzschmar, & Von Haaren, 2015) and to avoid deception. Downes & Lange (2015) demonstrated that inconsistent representation of content elements in visualizations are particularly problematic and that transparency in visualization development and presentation methods is a requirement for honest communication.

Landscape Visualization and Wicked Environmental Problems

Rittel and Webber (1973) outline a series of criteria that, collectively, constitute a class of societal problems for which traditional scientific approaches are destined to fail (Figure 20).

1. There is no definitive formulation of a wicked problem.
2. Wicked problems have no stopping rule.
3. Solutions to wicked problems are not true-or-false, but better or worse.
4. There is no immediate and no ultimate test of a solution to a wicked problem.
5. Every solution to a wicked problem is a "one-shot operation"; because there is no opportunity to learn by trial and error, every attempt counts significantly.
6. Wicked problems do not have an enumerable (or an exhaustively describable) set of potential solutions, nor is there a well-described set of permissible operations that may be incorporated into the plan.
7. Every wicked problem is essentially unique.
8. Every wicked problem can be considered to be a symptom of another problem.
9. The existence of a discrepancy representing a wicked problem can be explained in numerous ways. The choice of explanation determines the nature of the problem's resolution.
10. The social planner has no right to be wrong (i.e., planners are liable for the consequences of the actions they generate).

Figure 20. Distinguishing characteristics of wicked problems. (From Rittel and Webber, 1973)

The wicked problem construct has been used to characterize a variety of environmental problems, including eutrophication (Thornton et al., 2013), nonpoint source water pollution (Patterson, Smith, & Bellamy, 2013), climate change (Kazlauskas & Hasan, 2010; Curran, 2009), coastal vulnerability (Moser et al., 2012), fisheries science (Lackey, 2017), forest management (Balint, 2011; Carroll and Daniels, 2017), and multiple threats to the oceans (Paasche & Bonsdorff, 2018). In many of these examples, the "wickedness" draws from the fact that environmental resources fall outside of traditional decision models, and that the resources that society (as a whole) values *collectively* are undervalued by members of society *personally*. This "Tragedy of the Commons" (Hardin, 1968) has been the basis for environmental regulation of pollution of air, water, and land resources.

Increasingly, natural resource management strategies attempt to simultaneously consider multiple factors or outcomes resulting from management decisions. Adaptive management approaches to managing ecosystems are now commonplace, with recognition that ecosystems are complex and unpredictable in their response to management actions. Recommended management approaches to wicked problems are now emerging (DeFries & Nagendra, 2017), with a growing recognition of the protection of ecosystem services as an end goal and participatory planning as a means to that end (Davies et al., 2015).

As discussed in the background chapter, "geodesign" as a landscape planning framework has emerged over the past decade as an approach for combining geographic sciences, information technology, design principles, and people/stakeholders in the environmental planning process (Steinitz, 2012). Geodesign includes an understanding of landscape processes, impacts of management, and change that would result from design decisions at multiple scales.

Geodesign, and geo-inspired storytelling, game-playing, and exploration have been proposed as approaches to address wicked problems (Orland, 2016). Relatedly, recommendations for user-oriented visualization software have emerged to address wicked problems (Winters, Cushing, & Lach, 2016; Cushing, Winters, & Lach, 2015).

This proposed research connects elements of *geodesign* to address *wicked environmental problems* that are manifested as *changes to the landscape* that can be *visualized* in various forms.

Participatory Planning and Landscape Visualization

Participatory planning settings are not unique to a specific discipline. Some of the issues associated with the use of landscape visualization in participatory planning are therefore generic and relevant in a variety of application settings. Warren-Kretzschmar & Von Haaren (2014) found that, for public engagement, landscape visualizations can improve stakeholder participation since they can provide a familiar image for discussion and collaborative decisions. Wissen (2007) found that realistic landscape visualizations evoked a high degree of connection to the place being visualized and were useful for collecting local knowledge in participatory planning workshops. Lovett, Appleton, Warren-Kretzschmar, & Von Haaren (2015) emphasize that it is preferable to employ visualizations at multiple stages of the planning process as opposed to just unveiling them as finished products at the end.

In a survey of literature published in 2001, Al-Kodmany found that computerized visualization tools could enhance public participation in planning, but they sometimes acted as a deterrent to drawing stakeholders into meaningful interaction with the data or with each other. Similarly, Hayek, Neuenschwander, & Grêt-Regamey (2012) found that realistic visualizations were less suitable for generating *new* ideas in the planning process.

Environmental Education Applications

Much of the environmental education research associated with landscape visualization has focused on interacting with virtual worlds. Since landscape visualization may or may not involve immersive experiences, caution should be exercised when transferring results from these studies to interactive 3D applications in general. Interactive landscape visualizations, however, offer many of the same features as virtual worlds regardless of the degree of immersivity, including the provision of collaborative settings, a change from typical classroom learning, and remote participation possibilities (Bartle, 2004).

Loke (2015) conducted a literature review to identify theories of learning that are relevant to virtual worlds. Results of the review suggested that there are four learning mechanisms that are applicable: reflection, verbal interactions, mental operations, and vicarious experiences. Relatedly, Chen (2008) characterized a set of literacy skills that are relevant in virtual worlds: transmedia literacy, inquiry skills, and participatory skills.

Environmental education (as opposed to education in general) may be particularly appropriate for landscape visualization applications. Markowitz, Laha, Perone, Pea, & Bailenson (2018) found that immersive virtual landscapes led to greater inquisitiveness about climate change issues. Comparable results were obtained by Barbalios, Ioannidou, Tzionas, & Paraskeuopoulos (2013) in experiments among students investigating a virtual lake ecosystem impacted by neighboring farmers.

Working in virtual 3D environments has been suggested as an alternative to field trips. Ketelhut & Nelson (2010) investigated whether virtual inquiry could substitute for physical inquiry among seventh graders. Although results were mixed, initial evidence suggested that virtual settings could engage students as well as or better than physical experimentation.

From the landscape visualization training perspective, Yin (2010) evaluated the state of GIS and 3D visualization in graduate-level planning programs and developed a series of recommendations to expand their use. Included were recommendations for dealing with changing technology, expensive software, and how to leverage visualization in collaborative settings.

Landscape Visualization Applications from Environmental Disciplines

The following provides an overview of examples of the application of landscape visualization to address a variety of natural and cultural resource subjects.

Agriculture. Warren-Kretzschmar & Von Haaren (2014) investigated the visual impacts of land use change in agricultural landscapes through case studies, interviews, and quasi-experiments in different participatory settings. They found that farmers could benefit from easy-to-use tools that could simulate change at the landscape scale. Through a multiple case study design, Schroth (2007) leveraged 3D landscape visualization to represent various scenarios of landscape change and found that interactive navigation was important for stakeholders to understand the magnitude of landscape change.

Climate and coastal. Visualizing the place-based impacts of climate change has become a typical communication goal, particularly in coastal and flood-prone regions (Jude, 2008; Yang, 2016). This is sometimes combined with urban planning and geodesign strategies to show alternative scenarios and impacts of design decisions. Wu and Chiang (2018), for example, used participatory workshops to gather public opinion regarding the communication effectiveness of flood resilience strategies in Tainan City, Taiwan. Similarly, Macchione, Costabile, Costanzo, & De Santis (2018) developed a 3D landscape visualization tool for flood risk management and hazard communication in a case study conducted in Calabria, Italy.

Sea level rise associated with climate change can be visualized to highlight inundation in coastal areas. These visualizations can be particularly compelling and even dramatic in showing sea level rise impacts to local stakeholders (Sheppard, 2012; Fleming, Schmidt, & Cary-Kothera, 2016; Daniels, 2018). Newell & Canessa (2017) further investigate the understandings and perceptions of different stakeholder groups in coastal settings and provide recommendations for visualization interactivity based on a deeper understanding of these user groups.

Several studies have investigated the impacts of different modes of presentation of climate change information (Burch, Sheppard, Shaw, & Flanders, 2010; Schroth, Pond, & Sheppard, 2015 – see Figure 21). Posters and slideshows of visualizations had the greatest longevity in longitudinal studies and had the added benefit of being reusable in different stakeholder involvement settings.

Figure 21. Simulation of flooding and greenhouse gas simulation scenarios. (Image credit: Burch, S., Sheppard, S. R. J., Shaw, A., & Flanders, D. (2010). Planning for climate change in a flood-prone community: municipal barriers to policy action and the use of visualizations as decision-support tools. *Journal of Flood Risk Management*, *3*(2), 126–139).

Forestry. Landscape visualization has been used in forestry applications since the 1980s. The visual impact of future forest management scenarios is well suited to landscape visualization software. The ability to generate multiple panoramic views to assess the impacts of forest management can be exceptionally informative (Smith, Bishop, Williams, & Ford, 2012).

Lewis and Sheppard (2006) found that 3D visualizations of forest management resulted in a better comprehension of future landscape conditions by indigenous communities than did 2D maps and reports and that the 3D visualizations led to more in-depth discussions with stakeholders.

Although forest or tree cover can be procedurally simulated over large areas, they can also be generated based on detailed georeferenced data for individual tree locations. Schroth et al. (2011) used a detailed representation of the characteristics of individual trees and forest stands in British Columbia to populate a visualization with a high degree of accuracy and concluded that 90% of stakeholders in a planning workshop found that the detailed landscape images were helpful or very helpful.

Conservation and green space planning. Although conservation biology and landscape ecology principles have been applied to land use planning at multiple spatial scales (Drumstad, Olson, & Forman, 1996), 3D landscape visualization in conservation planning has lagged other application areas. Perkl (2016) developed a customizable tool to link local landscape conditions to wildlife corridor design based on the requirements of particular species and then visualized the results in 3D.

Urban planning and geodesign. Rosa (2014) utilized landscape visualization to support the evaluation of various geodesign scenarios on the provision of ecosystem services in an urban environment. Rosa's study was one of the few that combined impacts on ecosystem services and scenario implementation *cost* implications. Ecosystem service trade-offs associated with sustainable urban planning were also the focus of an investigation by Grêt-Regamey, Celio, Klein, & Wissen Hayek (2013). Their case study investigation looked at the use of interactive sliders to explore ecosystem service impacts under various urban design proposals.

Pauditšová & Slabeciusová (2014) found that both 2D and 3D models of cities and surrounding landscapes serve an essential role in communicating negative impacts on the environment as well as approaches for mitigating those impacts. Through a series of case studies, Davis (2016) found that *immersive* geodesign helped bridge the communication gap among multiple stakeholder groups.

Neuenschwander, Wissen Hayek, & Grêt-Regamey (2014) looked at the integration of urbanization patterns and ecosystem services using quantitative indicators. The corresponding 3D visualizations were helpful in the understanding of ecosystem services among stakeholders with different backgrounds (see Figure 22).

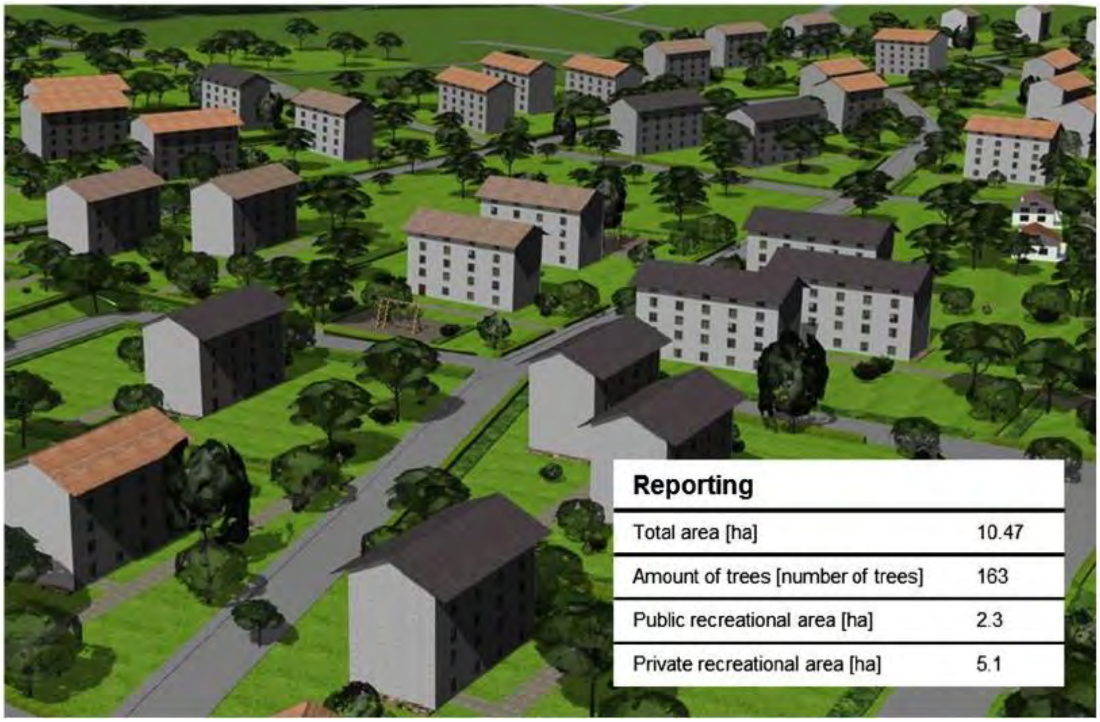


Figure 22. Urban green space scenario used in conjunction with indicators to assess ecosystem services (Image credit: Neuenschwander, N., Wissen Hayek, U., & Grêt-Regamey, A. (2014). Integrating an urban green space typology into procedural 3D visualization for collaborative planning. Computers, Environment and Urban Systems, 48, 99-110.). Reprinted with permission of the author.

Finally, Billger, Thuvander, & Wastberg (2017) conducted a thematic literature review to identify ongoing visualization challenges in urban planning and how visualization tools can support dialogue among stakeholders. Included in their findings is a recognition that there are organizational preparedness issues associated with the adoption of visualization tools, including competence in working with visualization tools and organizational access to tools and technology.

Environmental and visual impact assessment. As has been discussed, visualization can be useful to communicate to different stakeholder groups with varying levels of technical and subject matter expertise (Winters, 2015).

GIS is commonly used for visual impact assessments through viewshed analysis. Increasingly, 3D visualization is used to illustrate the real-world impacts from the construction of new features and their visibility from various vantage points. Wind farm (Danese, Las Casas, & Murgante, 2008) and wind turbine (Lange & Hehl-Lange, 2005) visibility have been the focus of case studies and participatory planning workshops. Landscape visualization has been particularly useful for revealing potential conflicts early in the planning process.

Landscape visualization has also been used to evaluate the “attractiveness” of the landscapes under different scenarios. Lange & Hehl-Lange (2005) conducted surveys asking stakeholders to rank a series of landscape scenarios reflecting a planning emphasis on agriculture, recreation, and nature conservation. They found that the stakeholders scored scenes that include features such as orchards, isolated trees, shrubs, and forests higher than those where buildings were dominant or where vegetation was lacking.

Estuarine and marine. Rehr, Williams, & Levin (2014) explored marine habitat restoration scenarios using visualization. Specifically, they were interested in whether users could distinguish variations in seagrass density and its spatial extent. They found that substantial differences in the spatial extent of the resource could be communicated effectively using visualization but were not effective to communicate marginal changes in seagrass density.

Seabed visualization has been the focus of other research as well. Canessa (2008 – Figure 23) evaluated various opportunities and challenges of geovisualization for marine planning, including multiple technologies and techniques (GIS, landscape visualization, ocean modeling, gaming, virtual reality). Canessa emphasized that the choice of any of these techniques should be informed by user research prior to selecting a technological approach.

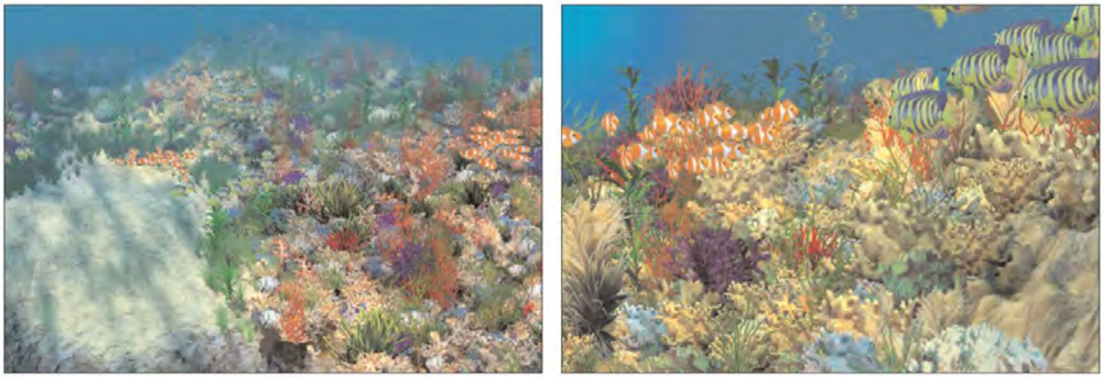


Figure 23. Coral reef seascape visualization. (Image credit: Canessa, R. (2008). Seascape geovisualization for marine planning. Geomatica, 62(4), 375-392.)

Barruos (2014) combined bathymetry and other geospatial data to investigate options for underwater navigation using game engine technology. He found that certain visualization navigation aids were more effective than others, adding that participants in the study found some navigation aids to serve little purpose and just added clutter to the interface.

Resch, Wohlfahrt, & Wosniok (2014) investigated the specific challenges of visualizing 4D marine geodata on the web, including defining usability criteria and an assessment of the appropriate base technologies for processing and rendering temporal data.

Finally, Portman (2014) described the unique challenges that remain in visualizing submerged marine environments and the role visualization plays in environmental communication, noting the need for further research on the use of advanced GIS methods and their integration with virtual reality applications.

History and archaeology. In addition to visualizing future condition yet to be realized, landscape visualization has also been used to recreate historical settings. Cajthaml & Tobiáš (2016) developed 3D scenes through procedural modeling that supplemented a historical 2D atlas of Czechoslovakia (Figure 24). Sullivan (2017) integrated 3D modeling with GIS analysis to investigate the visibility of monuments at ancient sites in Egypt, arguing that the 3D experience leads to greater contextualization of historic sites than would be accomplished through 2D maps.

Landscape visualization has also been used to recreate the historical conditions of the environment before human manipulation. Beattie (2014) leveraged 3D visualization models and a variety of historical GIS datasets to reconstruct the historical landscape of the Ballona Creek watershed in Los Angeles. The resulting visualizations can help planners with an understanding of the historical perspective of development as well as the possibility of a trajectory into the future.

Figure 24. Procedural reconstruction of an historic urban landscape in a web-based historical atlas of Czechoslovakia (Image credit: Cajthaml, J., & Tobiáš, P. (2016). 3d Procedural Reconstruction of Urban Landscapes for the Purposes of a Web-Based Historical Atlas. International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences, 42(2/W2), 41.). Reprinted with permission of the author.

Land Trusts and Land Conservation Mapping

Land Trusts and Local Land Conservation

The Land Trust Alliance (2017) defines a land trust as a "nonprofit organization that, as all or part of its mission, actively works to conserve land by:

- Acquiring land or conservation easements (or assisting with their acquisition), and/or
- Stewarding/managing land or conservation easements"

Land trusts protect land through the acquisition of interests in property – either through fee simple acquisition or the acquisition of conservation easements. The land trust "movement" began with the formation of the Trustees of Reservations in Massachusetts in 1891. The proliferation of land trusts and their role in land conservation accelerated in the latter half of the twentieth century (Brewer 2003), and they are now viewed as a critical partner in a national land conservation strategy (U.S. Department of the Interior 2022).

The 2020 National Land Trust Census (Land Trust Alliance 2022a) estimates that there are 1281 active land trusts operating in the United States, and they have been responsible for the protection of over 61 million acres as of 2020. (Land Trust Alliance

2022a). Figure 25 shows the locations of land trusts operating throughout the lower 48 states.

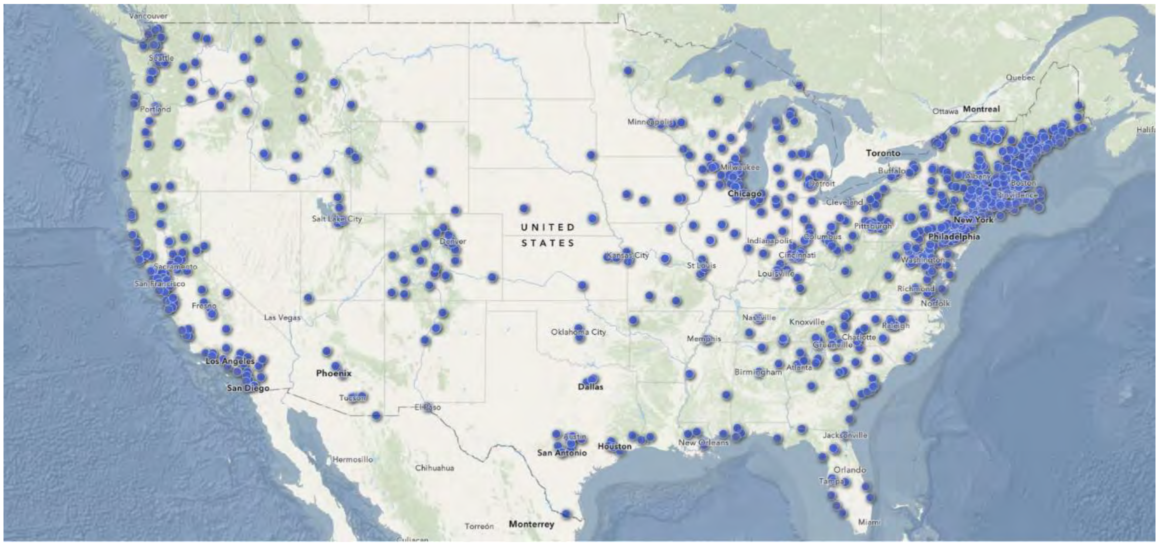


Figure 25. Land trusts of the United States. (Source: Land Trust Alliance Find-a-Land-Trust)

Map Use by Land Trusts

Maps have been a critical tool for land trusts for decades. Map uses have ranged from simple location maps to maps serving legal purposes (e.g., metes and bounds survey) to a variety of parcel and landscape scale natural resource uses (Byers and Ponte 2005). Often, the content of land trust maps can be associated with the mission of the land trust and conservation project acceptance criteria. For example, a land trust may strive to protect important forest, agricultural and historic properties in a region. Correspondingly, maps highlight the location of these resources.

Increasingly, geographic information systems are viewed as a vital resource in land trust operations. Robertson (2021) suggests GIS based maps for both external and internal uses of a given land trust.

Suggested maps for external use include:

- Geographic focus of organization (land trust service area)
- Accomplishment's map

- Individual maps for impact areas such a climate resilience, agricultural preservation, or development pressure
- Current projects
- Program or initiative maps
- Maps for fundraising

Suggested maps for internal use include:

- Potential project locations
- Donor base
- Easement monitoring maps
- Partnerships or collaborations
- Demographics and natural resources

The appropriate scale and extent of maps is dependent on the communication purpose. The investigation of a variety of maps accessible on land trust websites nationwide has resulted in two general presentation scales of content – (1) landscape or regional scales and (2) local or parcel scales. Admittedly these terms don't capture the full range of mapping needs for land trusts, but they provide some guidance for connecting map scale to communication purpose. For landscape or regional scale purposes, the emphasis is typically on the *context* of a land conservation project or of the topical focus of the map. For local or parcel scale purposes, the focus is often on the *content* of the project or parcel itself. This "scale" distinction will be discussed further in Chapter 3.

Increasingly, parcel-based maps are important. These can contain property attributes such as land and improvement values, zoning, and other assessment records. They may also contain parcel-based natural resources information. This can include land use and land cover characteristics, conservation benefits or ecosystem services metrics (Maryland Department of Natural Resources 2018), or other values useful for assessing a given parcel's contribution to an overall landscape conservation strategy. This information can be used to assess both costs and benefits associated with the protection of a given tract of land. For example, Messer and Wolf (2004) leveraged a parcel data base of real estate values and ecological attributes to investigate land conservation optimization for a land trust in northern Maryland.

Place vs. space. Land trusts often have a local focus, and frequently originate from the motivation of local landowners and citizens who are interested in protecting a particular local landscape. These active participants feel a unique or personal connection to a given place that they deem worthy of protection. This recognition of the importance of "place" can resonate through a land trust's strategic plan as well as its operational focus. As such, the role of maps can transcend the traditional role of communicating geographic space to a role of communicating the importance of place. This distinction is particularly relevant to land trusts because the conservation values aimed for protection are specific and local. Space is an inherently more abstract concept than place and maps that support local conservation communication objectives may connect the personal "security" aspects of place more so than the open "freedom" characteristics of geographic space (Tuan 1977).

The personal connection to place can have both ecological and human dimensions. The conservation ethic espoused in Leopold's "A Sand County Almanac" (1949) focuses on personal interaction and experience and implies a connection to and respect for the land and stewardship of the land. This philosophical perspective directly aligns with the local land conservation motivation of land trusts and can be a recurring theme in map communication products.

Landscape character. Protecting "place" can extend beyond the ecological. In fact, many land trusts aim to protect "landscape character" or in some cases, "rural character". Landscape Character Assessment (LCA) can be defined as "the process of identifying and describing variation in the character of the landscape" (NatureScot 2019). LCA has been embraced more in Europe than the United States, but its underpinnings are particularly relevant to land trust mapping efforts. LCA generally involves some combination of mapping the three physical landscape components of landforms, land use/land cover, and settlement patterns. Collectively, these components can be used to capture landscape characteristics of interest to land trusts. This extends the scope of mapping beyond the ecological to the visual (see Figure 26).

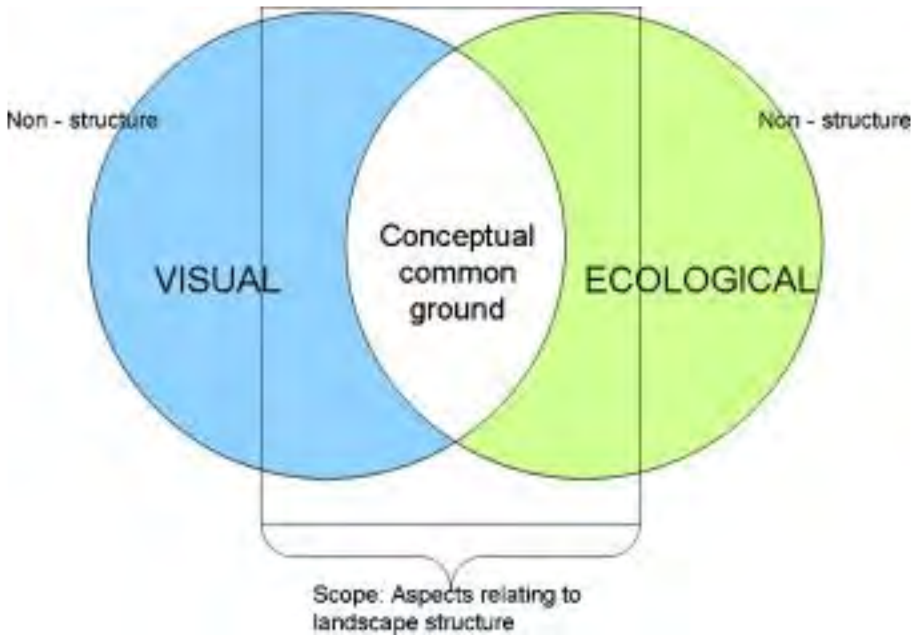
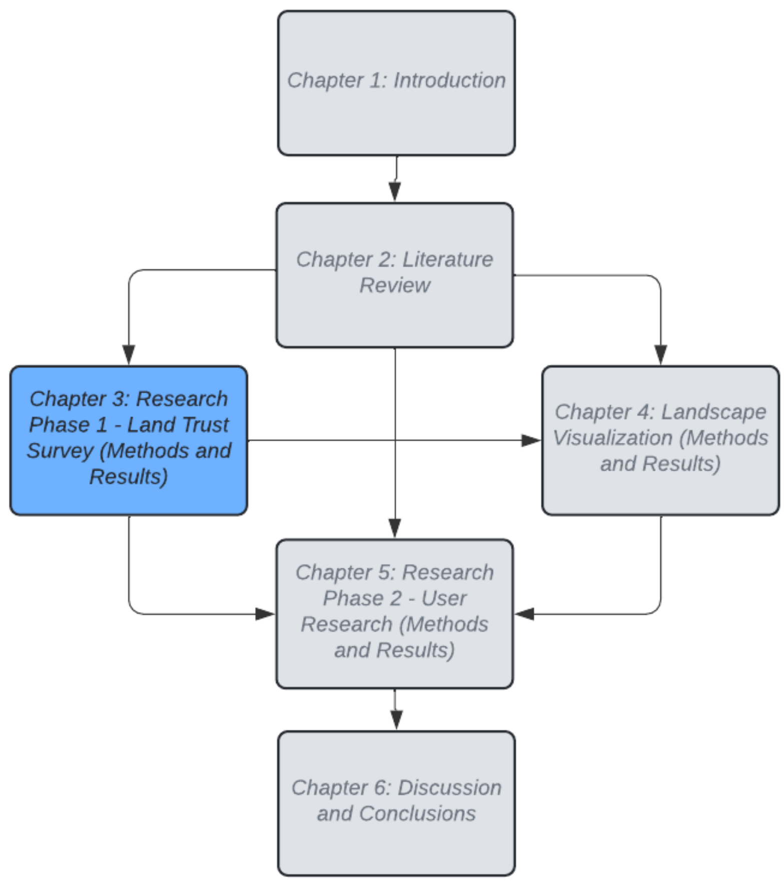


Figure 26. Conceptual common ground of visual and ecological landscape indicators (Image Source: Fry, G., Tveit, M. S., Ode, Å., & Velarde, M. D. (2009). The ecology of visual landscapes: Exploring the conceptual common ground of visual and ecological landscape indicators. *Ecological indicators*, *9*(5), 933-947.) Reprinted with permission of the author.

Visual elements can be introduced to land trust conservation objectives to serve additional conservation purposes. Preserving landscape or rural character is an inherently experiential objective. For example, a land trust could ultimately strive to emphasize the visual characteristics of a landscape to serve place branding objectives (de San Eugenio Vela, Nogué & Govers 2017). Place or "landscape" branding may ultimately support land trust marketing and fundraising initiatives. As a result, map products filling this role may emphasize landscape features critical to a communication objective aligned with a sales or persuasion goal. Understanding and communicating visually striking landscape attributes can help draw attention to conservation values important to the land trust. Not unlike State and National parks, land trusts may ultimately want to address what are essentially "tourism" interests. As with photography, maps can provide a tool for land trusts to address "tourist gaze" behaviors (Urry & Larsen 2011).

Chapter 3: Phase 1 – National Land Trust Mapping Survey

The purpose of this chapter is to describe the methods and results of Phase 1 of the research, which included a national survey of land trusts on their existing and potential use of maps for land conservation communication purposes.



Phase 1 Methods

An online survey approach was selected for this study to facilitate economical nationwide data collection from land trusts in a relatively short turnaround time. This phase of the research was cross-sectional without any longitudinal elements.

Since interactive maps are key elements of the research, distributing both the survey instrument and the associated web-based mapping application (story map) to a geographically dispersed audience could be easily done without a need for face-to-face interaction. A secondary reason for a survey-based approach is that the research was conducted during a pandemic that would make face-to-face interaction impossible.

Survey Population

Using the Land Trust Alliance's "Find-a-Land Trust" tool (Land Trust Alliance 2022b), a mailing list of approximately 1200 land trusts was assembled for the Phase 1 map use questionnaire. This initial list was developed by analyzing the public website and gathering publicly accessible email addresses. After removing duplicates there were ~930 email addresses that were used as the accessible population.

Survey Questionnaire

Phase 1 of the research focused on three topics related to the use and content of maps by land trusts: 1) communication purposes of maps, 2) conservation values depicted on maps, and 3) the potential use of maps to communicate landscape change. The survey used a combination of multiple-choice questions, rating questions, and open-ended questions aimed at gathering insights and use cases for the development of specific maps and scenes for Phase 2 of the research.

Survey Administration

Survey 123, a GIS based survey product that integrates with the software used to develop the complementary story maps, was chosen for the research based on functionality/data collection needs in addition to its integration with online mapping capabilities. The output of the survey was also used to develop georeferenced maps of survey responses based on zip codes of participants' organizations.

Phase 1 of the research was conducted in January – February 2021. Results were exported to Microsoft Excel and ArcGIS for the preparation of summary charts and maps.

Phase 1 Survey Results

The Phase 1 survey resulted in 161 responses from land trusts throughout the United States (see Figure 27). This represented a 17.3% response rate of the initial listing of 930 email addresses. Of the 161 responses 136 (14.6%) responded that they wished to be kept informed of the results of the study and 58 (6.2%) expressed an interest in participating in Phase 2 user research.

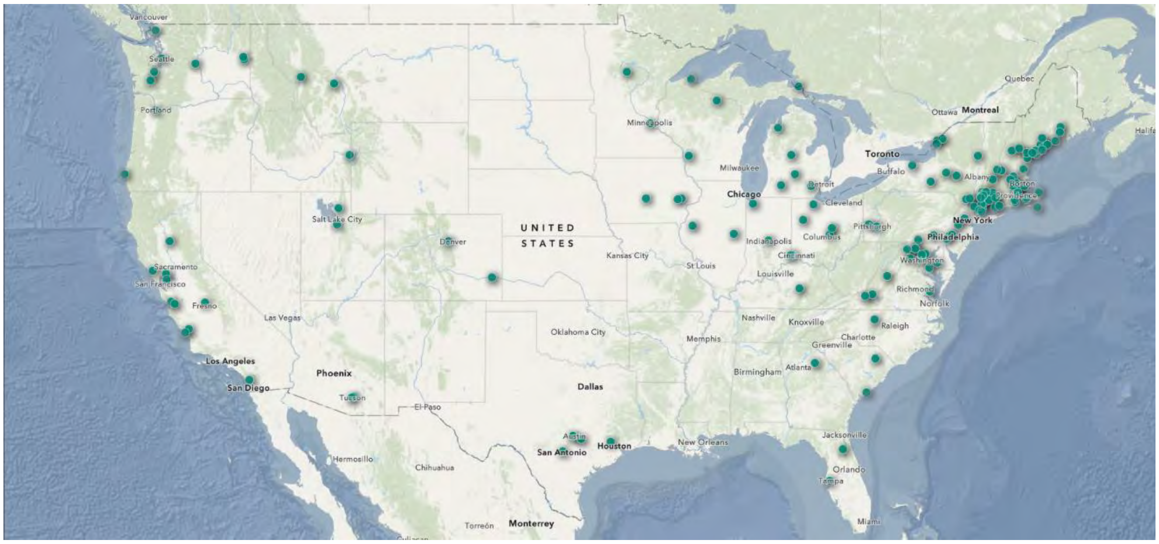


Figure 27. Locations of the headquarters (zip codes) of land trusts responding to Phase 1 of the survey.

Of the initial 930 email addresses, there were a number that were returned as bad email addresses. Also note that many/most of the email addresses in Phase 1 were for generic land trust email addresses (e.g., “info@bobslandtrust.org”) as opposed to specific staff contacts. It was not apparent how many of these email address inboxes were monitored on a regular basis.

This section summarizes the responses for Conservation Values (Figure 28), Communication Purposes (Figure 30) and Communicating Landscape Change.

Conservation Values

Following introductory demographic questions aimed at a general characterization (including size and historical accomplishments) of the land trust, each survey respondent was asked to indicate the types of conservation values that were the focus of conservation activities in the multiple-choice question shown in Figure 28.

Please indicate the conservation values the land trust aims to protect.

- ☐ Ecosystem Services
- ☐ Urban Open Space
- ☐ Forests
- ☐ Historical/Cultural Sites
- ☐ Rural Character
- ☐ Biodiversity
- ☐ Trails or other Recreational Resources
- ☐ Greenways/Habitat Corridors
- ☐ Wetlands and Water Resources
- ☐ Floodplain/Riparian Areas
- ☐ Viewsheds
- ☐ Farmland
- ☐ Other

Figure 28. Conservation Values Survey Question

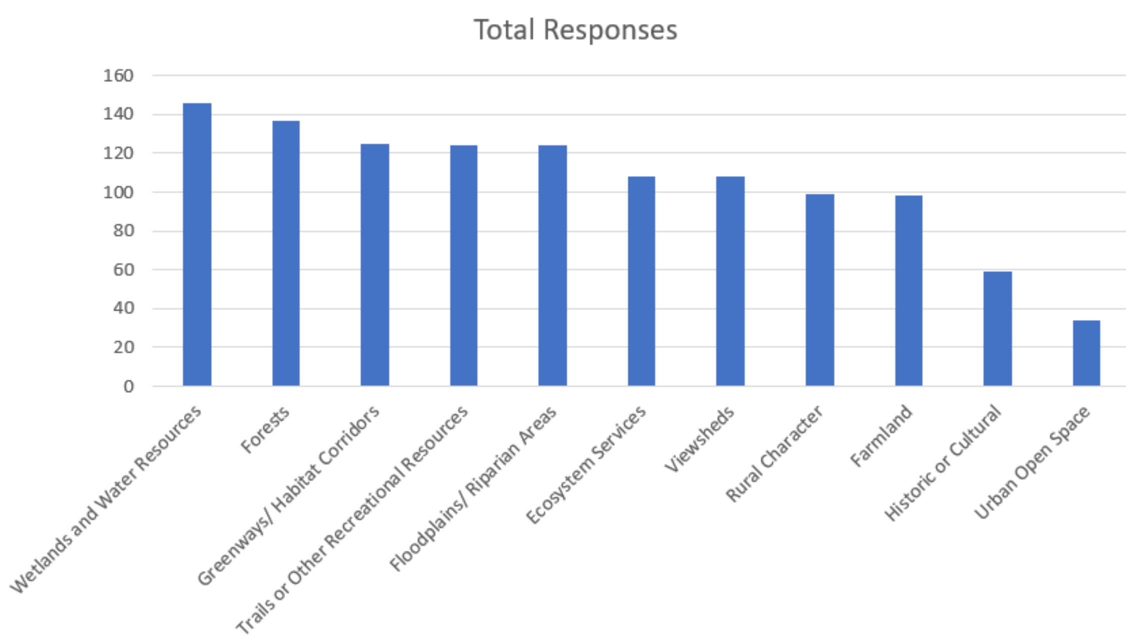


Figure 29. Conservation values of land trusts. **N**umber of Phase 1 responses associated with each category of values.

As can be seen in Figure 29, the most frequently cited conservation values included wetlands and water resources, forests, and greenways/habitat corridors.

Communication Purposes

The next question asked the survey respondent to rate, on a scale of 1 - 5, how important maps are to address land trust communication business cases (Figure 30).

How important are maps to land trust communication business cases?
Below are examples of how maps are, or could be, used by land trusts. For each example use case, please select the number of stars as follows:

1) Not important
2) Neither important nor unimportant
3) Important
4) Very important
5) Extremely important

__ Communicating land protection priorities
__ Fundraising/organizational support
__ Regional landscape assessment
__ Communicating vulnerability/potential impacts from development
__ Land trust service area delineation
__ Easement monitoring or stewardship plans
__ Communicating successes or accomplishments
__ Documenting conservation values
__ Property or parcel boundary location

Figure 30. Communications purposes of maps for land trusts survey question.

Communication purposes generally fall into two different spatial settings: map presentations featuring a specific property or parcel (such as a potential land conservation project) and purposes that focus on the landscape setting (where the focus is on the communication of features extending beyond a specific property or parcel). For purposes of this research, this distinction (see Table 2) was used in Phase 2 of the research where sample landscapes are evaluated for specific, context-driven communication purposes.

Table 2. Classifying map communication purpose to map "scale"

Parcel-centric Communication Purposes	Landscape-centric Communication Purposes
Property or parcel boundary location	Communicating land protection priorities
Fundraising/organizational support	Regional landscape assessment
Easement monitoring or stewardship plans	Land trust service area delineation
Documenting project conservation values	Communicating successes or accomplishments
Communicating vulnerability/potential impacts from development (parcel)	Communicating vulnerability/potential impacts from development (landscape)

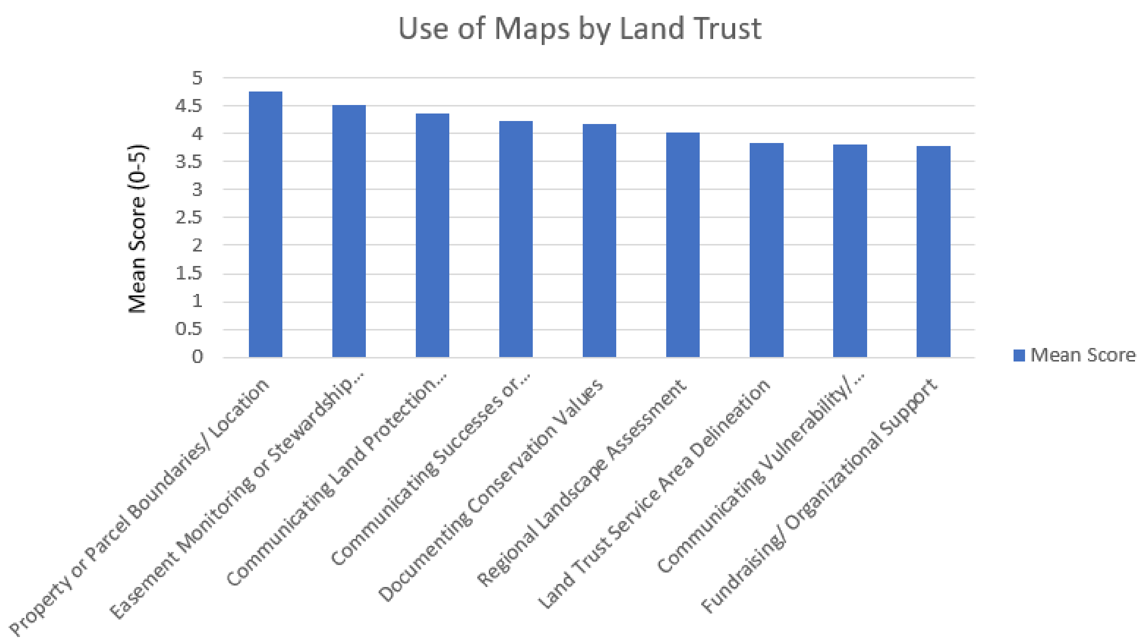


Figure 31. Communication purposes of maps used by land trusts. Mean response score based on a scale of 0 – 5 (0 = not important, 5 = very important)

The highest scoring communication purposes included property/parcel boundary locations and easement monitoring (parcel-scale applications) and communicating land protection priorities and communicating successes or accomplishments (landscape-scale applications – see Figure 31).

Communicating Landscape Change

Finally, each land trust was asked to indicate which of four landscape change scenarios was a focus of the land trust (Figure 32).

> In what scenarios do you or would you need to communicate landscape change?
>
> __ Historical land use change (e.g., impacts of population growth and development)
> __ Potential future land use change/alternative futures (e.g., future impacts of population growth and development)
> __ Potential climate change impacts (e.g., flooding, sea level rise)
> __ Alternative land management scenarios

Figure 32. Needs for communicating landscape change scenarios survey question.

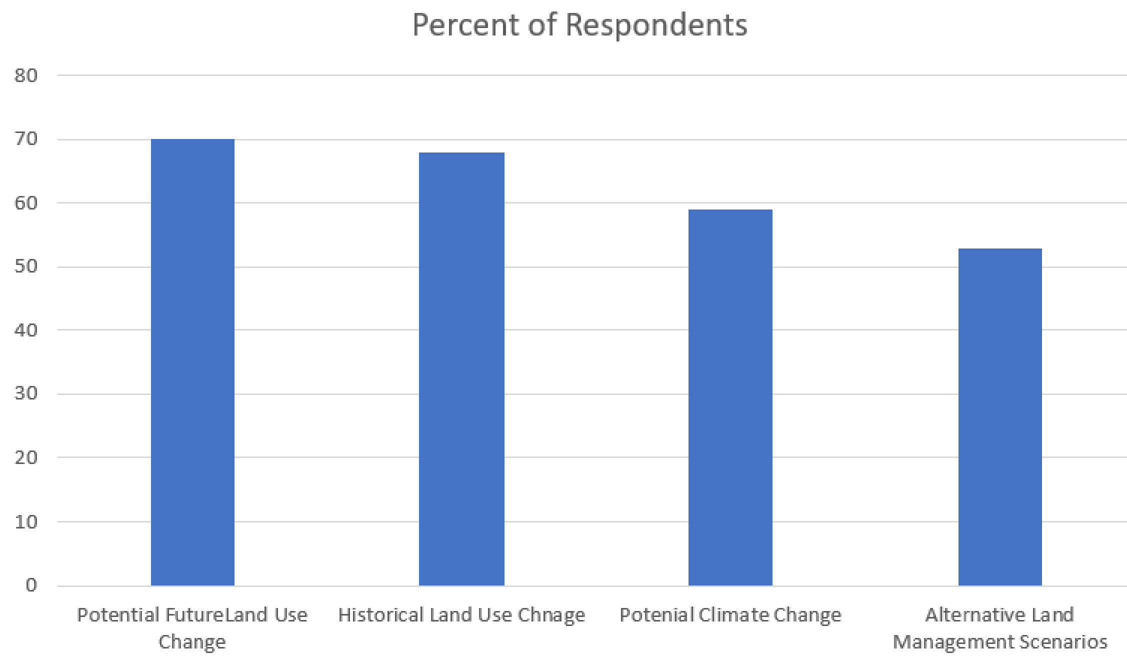


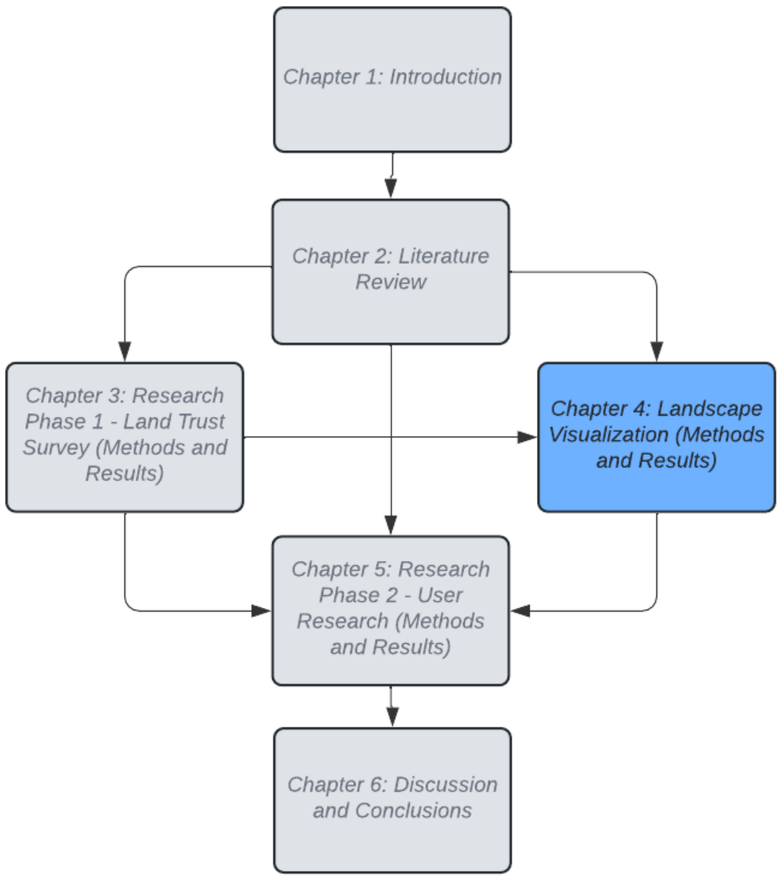
Figure 33. Percent of survey respondents indicating that communicating landscape change was important.

All four landscape change scenarios were recognized as important by at least 50% of the Phase 1 survey respondents (see Figure 33).

The results of these Phase 1 survey questions were used to inform landscape visualization scenarios used as part of Phase 2 of the research.

Chapter 4: Landscape Visualization Methods

The purpose of this chapter is to describe the methods and results of the landscape visualizations developed and used in Phase 2 of the research (Chapter 5).



The landscape visualization process used for this research integrates the Esri 3D basemap solution augmented with custom processes to enhance the representation of the chosen study area.

Study Area

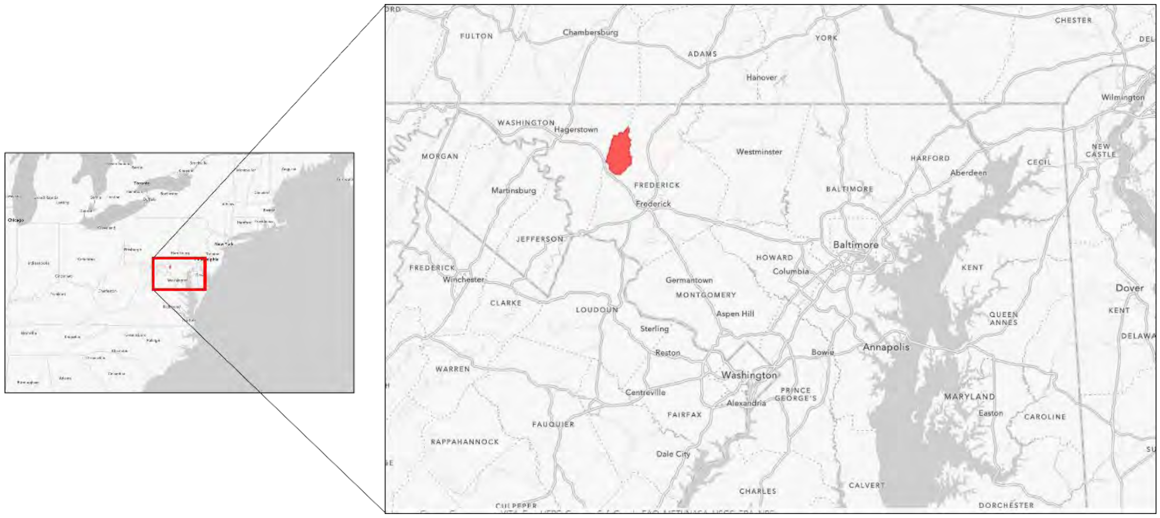


Figure 34. Regional setting of Upper Catoctin Creek study area

For purposes of this research, a study area was defined to represent the service area of a hypothetical land trust operating in central Maryland (Figure 34). The "Wolfsville Land Trust" aims to *protect the open space, resource-based industries, scenic and cultural resources, and rural character of the Upper Catoctin Creek watershed*. The Upper Catoctin Creek Watershed (ID 020700080101) is a United States Geological Survey 12 Digit watershed/hydrologic unit (United State Geological Survey, n.d.). The study area is approximately 33 square miles with elevations ranging from approximately 560 to 1900 feet above sea level. Land cover in the subwatershed is comprised of approximately 61% forestland and 29% agriculture, with the remaining area in developed land uses. There are a few small towns and settlements in the subwatershed, with the unincorporated community of Wolfsville (pop. 4195 in 2016) being the population center. Additional information on the study area can be found in Appendix A.

Within the Upper Catoctin Creek watershed are 16 smaller hydrologic units or "catchments". For purposes of this study, catchments are being used to simulate "landscape" scale map and scene applications. Local or "parcel" scale applications use parcel data obtained from the Frederick County Maryland GIS Department. See Figure

35 for portrayal of the study area (subwatershed - HUC12), landscapes (NHD+ catchments), and parcel boundaries.

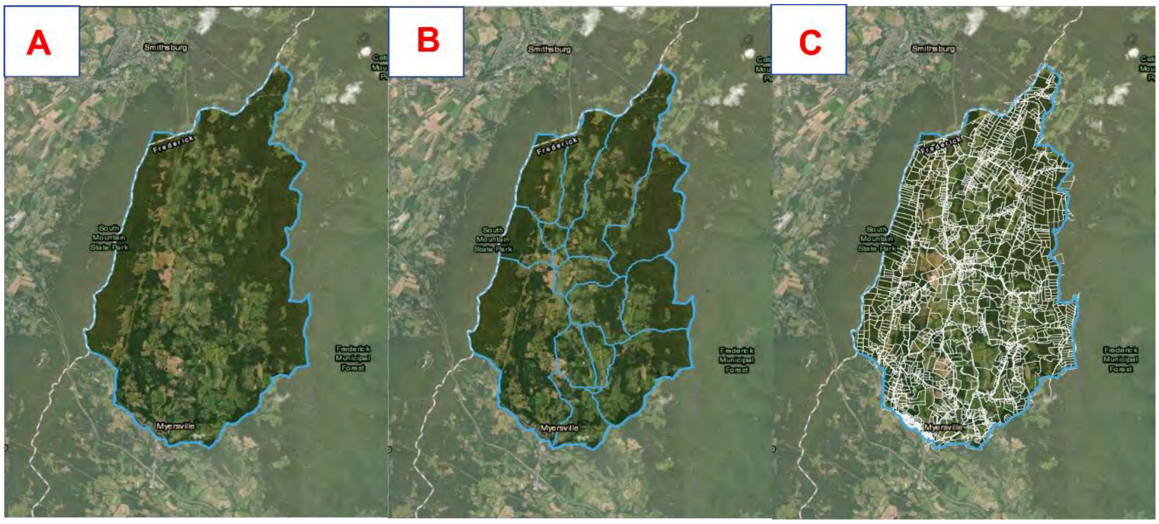


Figure 35. Hierarchical depiction of (A) study area, (B) landscapes/catchments, and (C) parcels.

Data Requirements

The primary data required to develop interactive 3D visualizations are LiDAR and building footprints. Quality Level 2 (QL2) or better is recommended to capture complex building shapes and for visually representative depictions of vegetation. QL1 LiDAR can also be used but, for three-dimensional modeling purposes, may lead to additional computational demands with marginal gains in realism.

LiDAR is used for defining height attributes of terrain/landforms, buildings and vegetation. As such it is key to depicting the vertical structure of the landscape. LiDAR is increasingly available throughout the United States and can be downloaded from The National Map (United States Geological Survey 2022) or from State mapping agencies and organizations. For purposes of this research, LiDAR was obtained from the Maryland iMAP LiDAR data download website (Maryland iMAP 2013). The date of the

Frederick County LiDAR was 2012, so wherever possible ancillary data was sought that was of similar temporal vintage.

The other primary dataset that is required for procedural modeling of landscape features is building footprints. Again, planimetric building footprint data is becoming increasingly available nationwide. Although they are often digitized from orthophotography, there are now machine learning algorithms that can extract building footprints from LiDAR. For purposes of this research, building footprints as a polygon GIS data layer were obtained from the Frederick County GIS Department (Frederick County GIS 2019).

Other GIS data can be used to complement or enhance features through draping on a 3D elevation surface. For purposes of this research any ancillary data that was draped on 3D elevation surfaces was also depicted on corresponding 2D maps to ensure comparability of maps and scenes used in Phase 2 of the research.

Overview of GIS Processing

The generation of 3D scenes requires a series of geoprocessing steps that transform LiDAR point clouds and building footprints into 3D models that can be draped onto 3d terrain. The following represents a high-level summary of the steps involved. Detailed GIS processing steps used in this research are captured in Appendix C.

1. Assemble and preprocess data for study area

Prior to any data processing or manipulation, appropriate files from National Watershed Boundary Dataset, National Hydrography Dataset, and planimetric features data to represent study area are accessed and downloaded (Figure 36).

The data is then clipped and reprojected to the appropriate coordinate system.

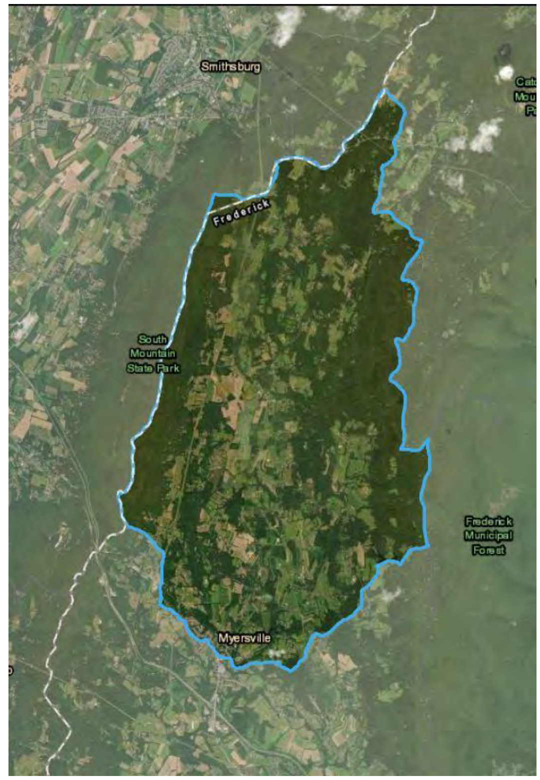


Figure 36. Study area used to establish boundaries for LiDAR and other geoprocessing.

2. LiDAR access and preparation

LiDAR data is typically accessed in a compressed format (i.e., LAZ file) and downloaded according to a tile structure that corresponds to the quality level of the data. In general, the higher the resolution of the LiDAR, the smaller the individual tiles will be. Figure 37 shows the LiDAR tile density for the Upper Catoctin Creek watershed.

If the LiDAR is downloaded as compressed files, it will need to be decompressed to LAS format for further processing (Figure 38).

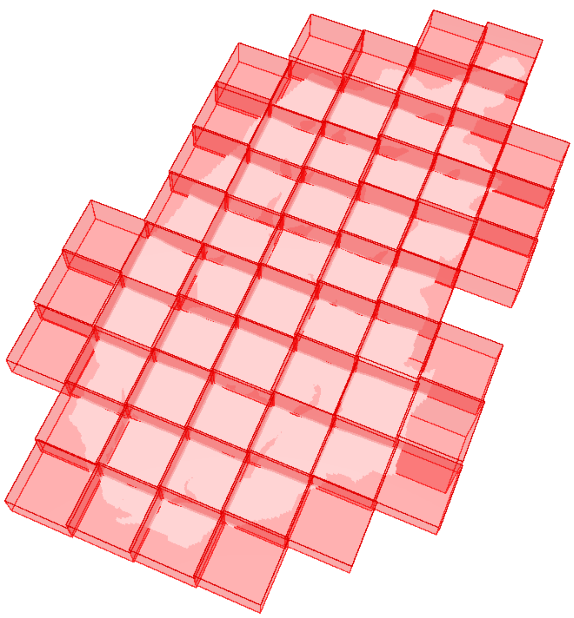


Figure 37. LiDAR tile footprint for study area.

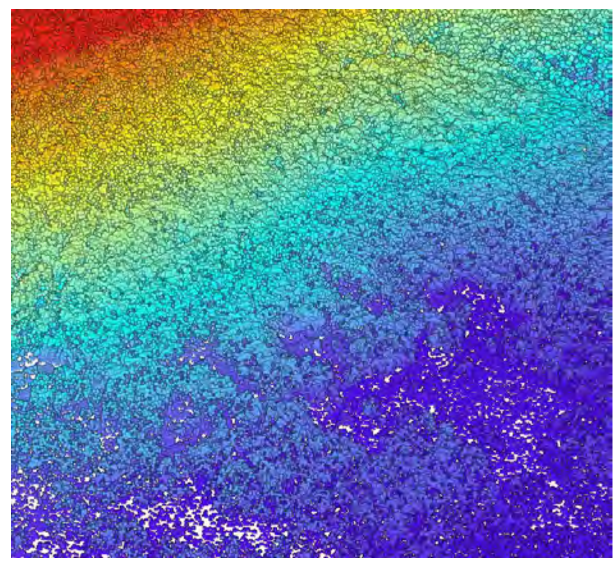


Figure 38. LiDAR point cloud after import.

3. Generate elevation surfaces from LiDAR

Elevation surfaces are published from the LAS dataset (DTM, DSM, nDSM) (Figure 39). These surfaces are used to add vertical elevation to (1) terrain (Figure 40), (2) buildings, and (3) vegetation.

Figure 389. Elevation models. A - Digital Terrain Model (Earth's surface). B - Digital Surface Model (elevation of objects on top of Earth's surface). C - normalized Difference Surface Model (height of objects on top of Earth's surface)

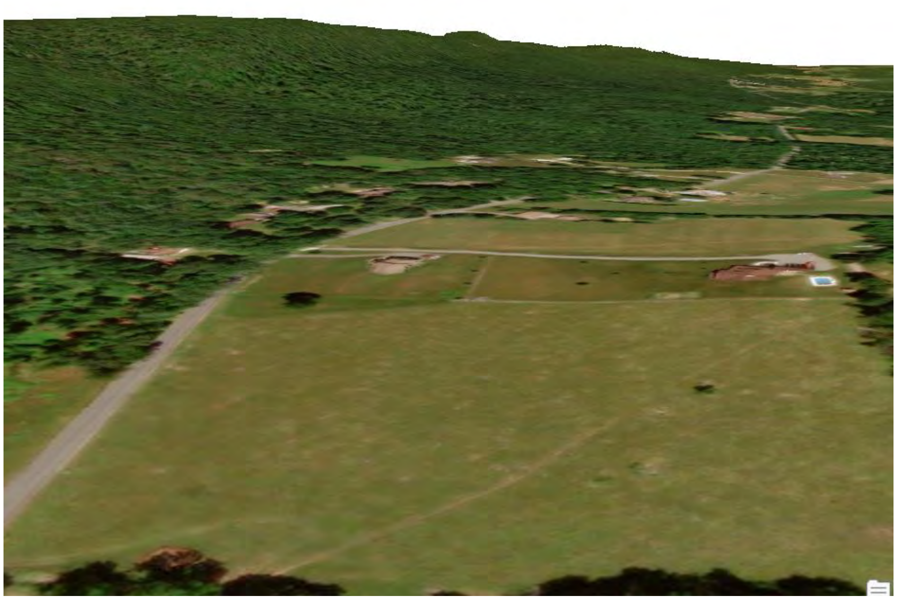


Figure 40. Image base map draped on Digital Terrain Model.

4. Publish building models

Building footprints are used to create 3D multipatch building models by vertically extruding the footprint shape to the height of the nDSM (Figure 41).

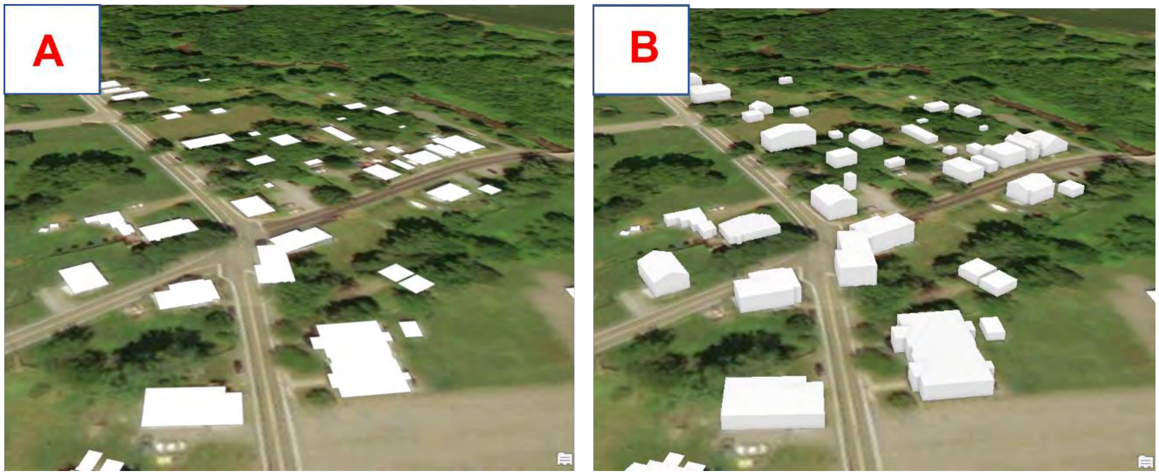


Figure 41. A - 2D Building footprints. B - 3D Multipatch building models.

5. Publish tree models

Trees and vegetation are generated by vertically extruding tree points from (1) LiDAR and (2) randomly generated points within forest polygons. (Figure 42A). Preset symbology is used to create tree models based on common species of Blue Ridge physiographic region. (Figure 42B)

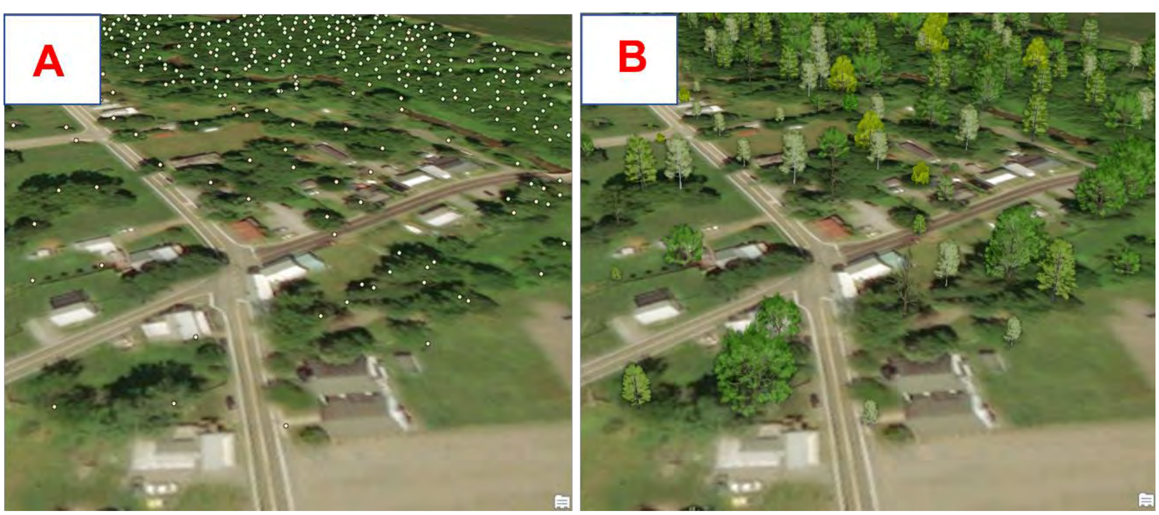


Figure 392. A – Vegetation rendered as 2D points. B – Vegetation points rendered as 3D tree models.

The resulting buildings and vegetation can be rendered on 3D terrain for a composite landscape view (Figure 43).


Figure 43. Composite 3D scene with building and vegetation models.

Web Application Development and Deployment

Three-dimensional features (buildings and vegetation) are uploaded to ArcGIS Online (AGOL) for (1) further cartographic and symbology refinement and (2) integration into interactive web scenes. For purposes of this research, extensive building detail was not necessary given the land conservation focus of the land trust. Therefore, LOD 2 buildings and shadows were used for examples utilized in Phase 2 of the research. When not already symbolized, trees were symbolized based on species' models native to the Blue Ridge physiographic region. See appendix B for species selection and relative abundance.

For purposes of this research, National Agricultural Imagery Program (NAIP) (USDA Farm Service Agency 2015) imagery was used for the base map for both 2D maps and 3D scenes. NAIP provides a high-resolution (1 meter) base map usable in both 2D maps and 3D scenes. Edge of pavement from Fredrick County GIS was added to both 2D maps and 3D scenes to enhance the depiction of roads.

Interactive web maps and web scenes for the specific questions contained on the Phase 2 survey (see Chapter 5) were generated and added to the corresponding story maps. The story maps for 2D maps and 3D scenes at both the landscape and parcel scales were assembled into four story map collections – one each for the four test conditions. Figure 44 shows the wireframe prototype relationship between the survey instrument and accompanying story map collection. Figures 45 through 48 provide static examples of maps and scenes developed for Phase 2 of the research and included within the story maps.

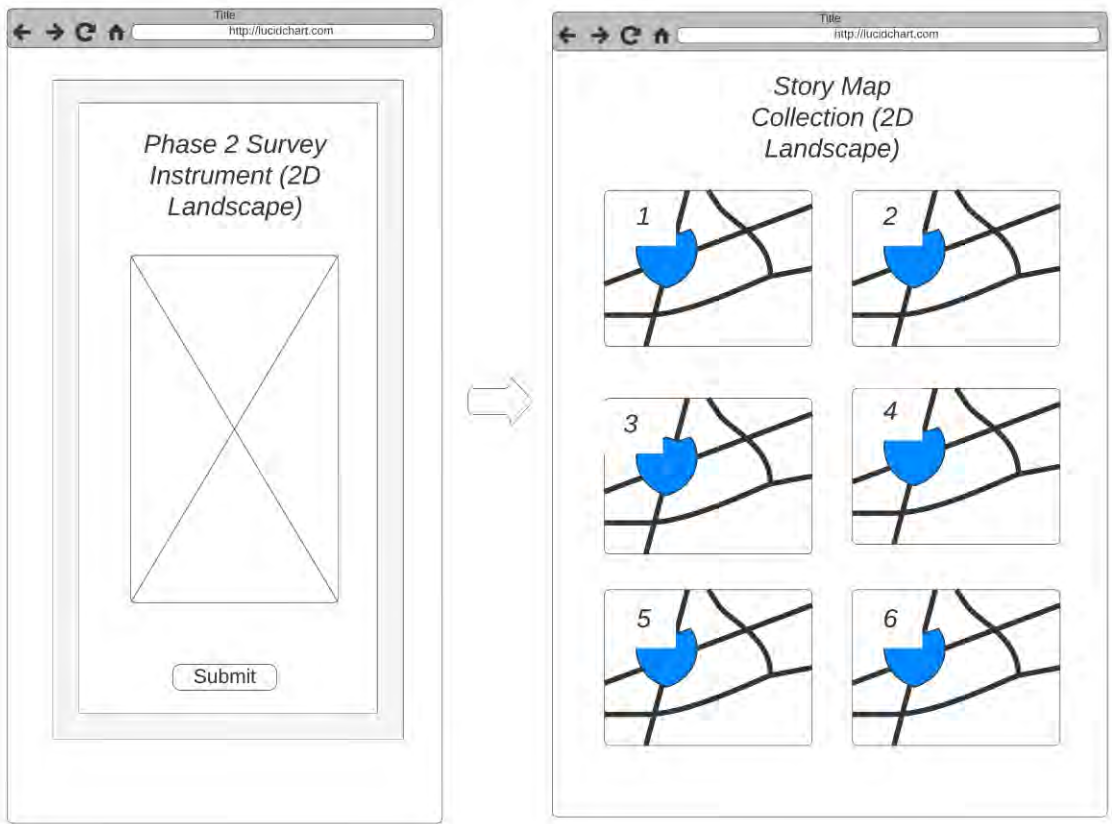


Figure 40. Wireframe of Phase 2 survey instrument and accompanying story map.

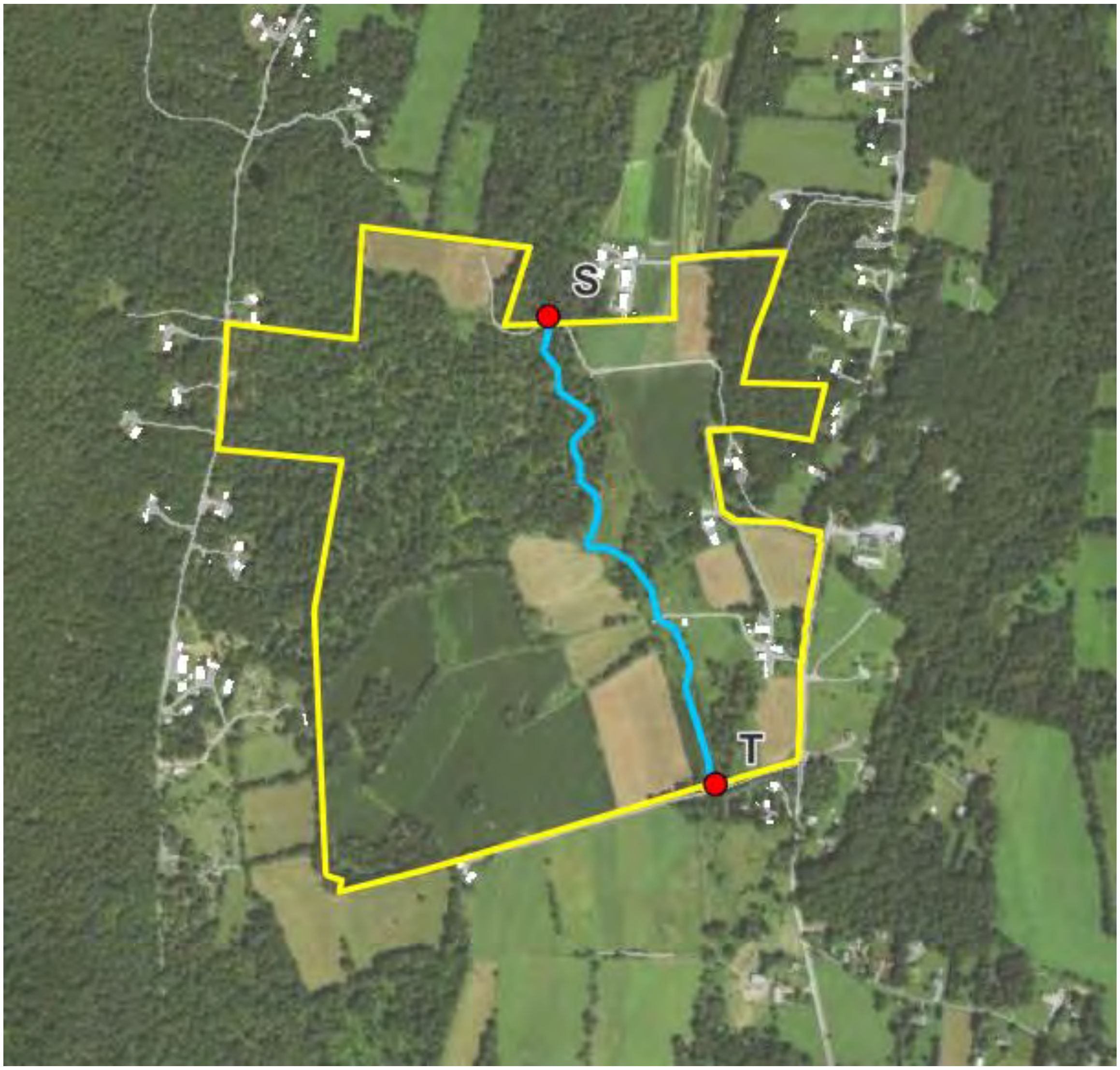


Figure 41. Static example of interactive 2D parcel map used in questions of Phase 2 of Research

Figure 42. Static example of interactive 2D landscape (catchment) map used in questions of Phase 2 of the research.

Figure 43. Static example of interactive 3D parcel map used in questions of Phase 2 of the research.

Figure 44. Static example of interactive 3D landscape (catchment) map used in questions of Phase 2 of the research.

Map and Scene Components

Web maps and scenes were developed in such a way as to (1) minimize or eliminate extraneous content and (2) provide basic interaction navigation capabilities.

Labels. Map/scene labels were limited to information needed to understand and respond to the survey questions. Where necessary, map/scene labels that were included contained identical content between 2D and 3D views.

Navigation aids. Navigation within maps/scenes was provided using on-screen navigational widgets provided by the software. These widgets were configured to ensure consistency among the multiple maps/scenes in each version of the survey instrument. Both 2D maps and 3D scenes contained "pan" and "zoom" capabilities enabling the user to navigate the position and zoom level of the interface. In addition, the 3D scenes provided an additional widget that enabled the user to tilt and rotate the view. These widget capabilities are common to most 2D maps and 3D scenes accessible on the web as of the writing of this dissertation.

Legends. Map/scene legends were included where necessary to understand and respond to the survey questions. The content of legends was limited to items necessary to address the question. Where necessary, map/scene legends that were included contained identical content between 2D map and 3D scene views.

Default camera position. For purposes of this research, both the 2D maps and 3D scenes use Web Mercator Auxiliary Sphere as the map projection. As with any conformal projection, directions, angles, and shapes are preserved. This projection is also commonly used in Google Maps. As a result, it provides a familiar display environment for online map users. However, Web Mercator is not designed to minimize distortions for distance and area calculations. For the 2D maps, the default camera position (map view) is from the overhead/top down. For the 3D scenes, the default camera angle is a perspective view. In each case the default display extent is set to include the entire geography of interest for that specific version of the test instrument (i.e., parcel or landscape).

Performance Issues associated with Web Maps and Web Scenes

Web maps and scenes were developed to ensure adequate interaction and rendering speeds on a modern desktop or laptop computer. Rendering of 3D material can be computationally intensive, which can lead to slow drawing/rendering performance on some systems. The 3D web scenes are accessed through ESRI's Scene Viewer. Minimum hardware requirements for acceptable rendering of web scenes are as follows:

> "For best performance, it is recommended that your browser have a minimum of 8 GB system memory and modern graphics hardware for 3D. Minimum requirements are a high-performance graphics card with at least 512 MB of video memory. For the best performance, it is recommended that you have a graphics card with at least 1 GB of video memory, especially for working with larger or more memory-intensive 3D scenes. High-performance, stand-alone graphics cards typically have better performance than integrated graphics cards." (ESRI 2021b).

As of the time of this writing, Scene Viewer supports the latest version of common browsers (Chrome, Firefox, Microsoft Edge) except for Safari, which does not yet have WebGL implementation optimized for memory-intensive applications (ESRI 2021b).

For purposes of this research, participants were advised not to complete the survey instrument on a mobile device. This was due to both processing requirements and the display limitations of smaller devices. However, the 2D map viewer, 3D scene viewer, and ArcGIS Story Maps collection all support responsive design, so it was technically possible to complete the Phase 2 survey on a mobile device.

Note: in September 2021, ArcGIS Online Scene Viewer was upgraded to WebGL2 for the rendering of 3D graphics (Mielke 2021). This research leveraged this upgrade for scenes used in the user research (see Chapter 5) phase of this project. Accordingly, 3D web scenes created for this research leveraged this new capability in Local Scenes in the WGS 1984 coordinate system. This substantially improved rendering speed of 3D scenes.

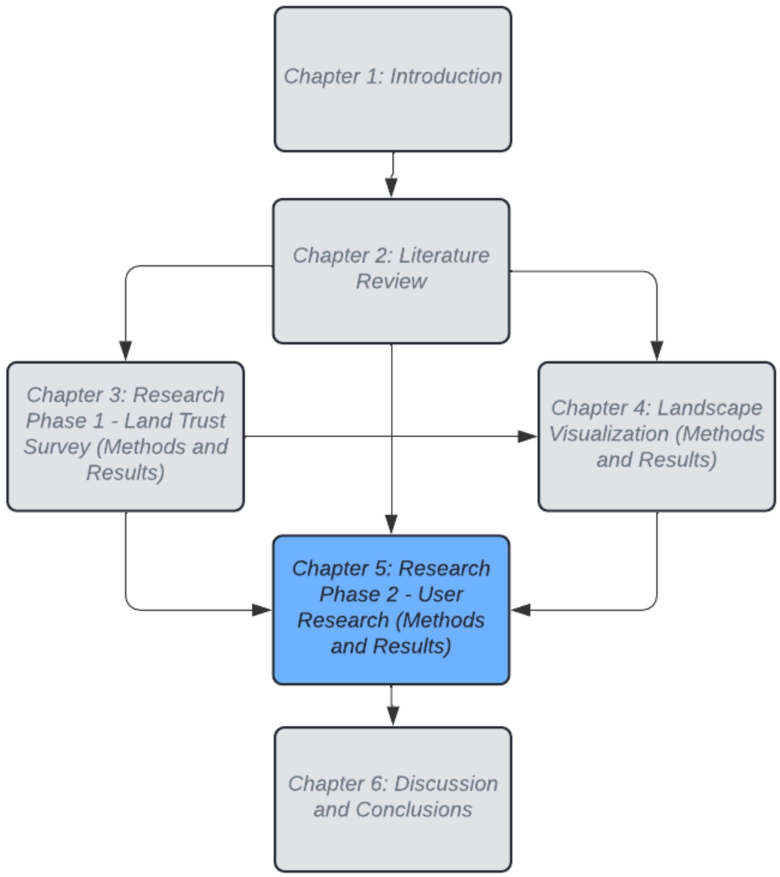
Story Maps and Story Map Collection

Published web maps and scenes were embedded into individual story maps for each unique combination of Phase 2 survey question and between-subjects factorial design grouping (see Chapter 5). The individual, question-specific story maps were embedded into four separate story map collections representing each group as follows: (1) 2D-landscape, (2) 2D-parcel, (3) 3D-landscape, and (4) 3D-parcel.

These story map collections became the test materials corresponding to the four distinct Phase 2 survey instruments. Please see items 1, 2, 3 and 4 in Appendix D to access the Story Map Collections.

Chapter 5: Phase 2 – User Research

The purpose of this chapter is to describe the methods and results of Phase 2 of the research.



Phase 2 Methods

The purpose of this study was to understand the relationship between map dimensionality (independent variable #1: two dimensions vs. three dimensions) and map scale (independent variable #2: landscape vs. parcel) on map effectiveness and map usefulness for land conservation communication purposes as evaluated by land trust professionals throughout the United States. Interactive two- and three-dimensional (2D and 3D) (independent variable #1) maps were developed for a hypothetical land trust (Wolfsville Land Trust) focusing on land conservation in the Catoctin Creek watershed in central Maryland. The maps were evaluated for both landscape-scale and parcel-scale (independent variable #2) communication purposes. The spatial scale context was important to this study because it was desired to determine if scale impacted effectiveness of 2D vs. 3D map representations.

The study leveraged a between-subjects 2x2 factorial design for Part 1 of Phase 2 (focusing on map effectiveness), followed by a Chi-square Test of Independence (the 2D and 3D research groups delineated in Part 1) to evaluate perceived map usefulness in a variety of land trust communication use cases. Data for both parts of Phase 2 were collected through an online survey in December 2021.

Phase 2 Experimental Design

Part 1 Design. The first part of the study (map effectiveness) asked participants to answer a series of questions based on their inspection of six maps. The questions were developed to represent a user's ability to address a range of operational tasks derived from published geovisualization exploration and communication taxonomies (See Wehrend and Lewis 2000 and Koua et al 2006 for examples. Additional discussion of map reading tasks is contained in Chapter 2). For purposes of this research, Appendix E identifies the tasks and associated survey questions aimed at map effectiveness. The questions had an independently derived answer (i.e., - "truth") to which an individual's response accuracy (dependent variable) were compared. Effectiveness was based on the mean score of the number of correct answers provided by each respondent. A total effectiveness score was calculated across the range of questions for which each participant provided a response (i.e., missing values were removed from the mean score calculation).

Part 2 Design. The second part of the study (map usefulness) asked respondents to rate map examples for their perceived usefulness via Likert rankings (dependent variable) for a variety of land conservation communication purposes. Five communication purposes were scored for landscape-scale applications and five were scored for parcel-sale applications in the questionnaire, although any one respondent was only asked to score either landscape or parcel depending on which version of the survey they received (based on random assignment of tests). Perceived usefulness for specific communication purposes was reported using a five-point scale (5- very good, 4 - good, 3 - fairly good, 2 - poor, 1 - very poor). A total usefulness score was calculated as the mean score for each respondent across the range of five example use cases.

Phase 2 Survey Design

Survey approach

As with Phase 1, interactive maps were key elements of the research. Therefore, a web-based survey and accompanying story map were developed for distribution to a geographically dispersed audience of land trust personnel throughout the United States. As an incentive for participation, participants with the first 75 completed responses were offered a $20 gift card (courtesy of the University of Baltimore Turner Research and Travel Grant program).

Survey pilot

Surveys associated with both phases of the research were piloted with staff representatives of the Maryland Environmental Trust (Phase 1) and colleagues of the researcher (Phase 2). For Phase 2, Pilot testing was aimed at determining usability issues with the survey forms themselves and included questions such as:

- Could you follow between the survey and the story map collection? Was that in any way challenging?
- Are the questions clear? Did you understand what was being asked?
- Did the answer options make sense in the context of the question being asked?
- How long did it take to complete your version of the survey?

For Phase 2 of the research, four distinct versions of the survey and corresponding story map were developed to facilitate the 2x2 between-subjects factorial design. The questions in the four instruments were identical except for references to the unique characteristics of the four conditions being evaluated.

The pilot resulted in several changes to the survey instruments, including corrections for inconsistencies among the instruments, typographical errors, and clarification of terminology. Each of the pilots was completed within a period (30 minutes or less) considered acceptable for the main study. As a result, piloting the survey did not result in changes to the overall length or organization of the survey.

Survey Population

Initially the total population for Phase 2 included those land trusts that participated in Phase 1 who included a valid email address in their response. However, as plans for Phase 2 came into focus (specifically the 2x2 between-subjects factorial design and the response rate from Phase 1), it became apparent that it would be beneficial to obtain a larger participating sample, so a different approach was developed as follows:

1) Include all Phase 1 respondents who included a return email address (147)
2) In addition, manually use the LTA Find a Land Trust tool state by state to obtain additional email addresses using the following process.
    (a) Only include land trusts who did not respond to Phase 1 (because Phase 1 emails had already been assembled)
    (b) Of those additional land trusts, identify if the land trust had staff listed on the website.
    (c) Of those with staff listings, identify if there were staff email addresses for individual staff members.
    (d) If there were staff email addresses, include up to three email addresses for any given land trust with preference given to the following:
        (i) Executive Director or Communications Director
        (ii) Director of Land Conservation or Land Stewardship
        (iii) GIS Staff Person
        (iv) Other
3) The resulting list (n = 1195) became the accessible population for Phase 2 of the study.

4) Based on the 2x2 factorial design, individual email addresses were then assigned to one of four testing instruments by selecting a random start and then assigning a number from 1 to 4 based on every 4th person on the list.

Testing Procedure

The surveys were conducted over the internet using custom Survey 123 instruments developed specifically for a land trust professional or volunteer staff audience. As with Phase 1, the survey included the survey instrument itself along with a supplementary map-based story map, which was used to portray the visual representations of interactive 2D maps and 3D scenes.

Questionnaire Design

The Phase 2 survey instrument contained six sections as follows: 1) survey home page, 2) introduction and University of Baltimore Institutional Review Board acknowledgement, 3) overview (name of land trust and zip code of land trust headquarters), 4) map effectiveness questions, 5) map usefulness questions, and 6) conclusion.

Map effectiveness questions were accompanied by a separate linked application (story map) that contained the examples maps for the study area. The map effectiveness questions were in a multiple-choice format. The map usefulness questions were in an ordered Likert format with five potential answers ranging from very poor to very good.

Table 3 describes the relationship of survey instrument questions to research hypotheses.

Table 3. Relationship of Phase 2 survey questions to research question variables.

Variable Name	Research Question	Item on Survey
Independent Variable 1: Dimensionality	Does dimensionality (2D vs. 3D) impact task success associated with communicating concepts?	See questions 1-14

Independent Variable 2: Spatial Scale	Does scale of application (parcel vs. landscape) impact task success associated with communicating concepts?	See questions 1-14
Dependent Variable 1: Task Success	How many questions are answered correctly?	See questions 1-14
Independent Variable 1: Dimensionality	Does dimensionality impact perceived usefulness of maps for addressing specific purposes?	See questions 15-20
Dependent Variable 2: Usefulness rating	How useful are 2D vs 3D maps?	See questions 15-20

Data Collection

The Phase 2 survey was conducted during December 2021. Data was collected through the Survey 123 application. Respondents were given three weeks to respond to the survey. After two weeks, a reminder email was sent to potential participants who had not yet responded. The full list of responses was exported to Microsoft Excel and SPSS for further processing.

Phase 2 Results

For the map effectiveness part of Phase 2, the between-subjects 2 x 2 factorial design resulted in the completed responses indicated in Table 4. Two outliers in the 3D Parcel group were identified, so the analysis was conducted with and without the outliers. The results did not change, so a decision was made to include the outliers in the analysis to maximize the count of records in that group (which already contained the smallest number of records among the four groups).

Table 4. Cross-tabulation of number of completed responses for each combination of factors in the map effectiveness analysis within Phase 2.

Dimension * Scale Crosstabulation

Count

		Scale		
		Landscape	Parcel	Total
Dimension	2D	22	26	48
	3D	29	21	50
Total		51	47	98

The geographic distribution of responses by combination of factors can be seen in Figure 49.

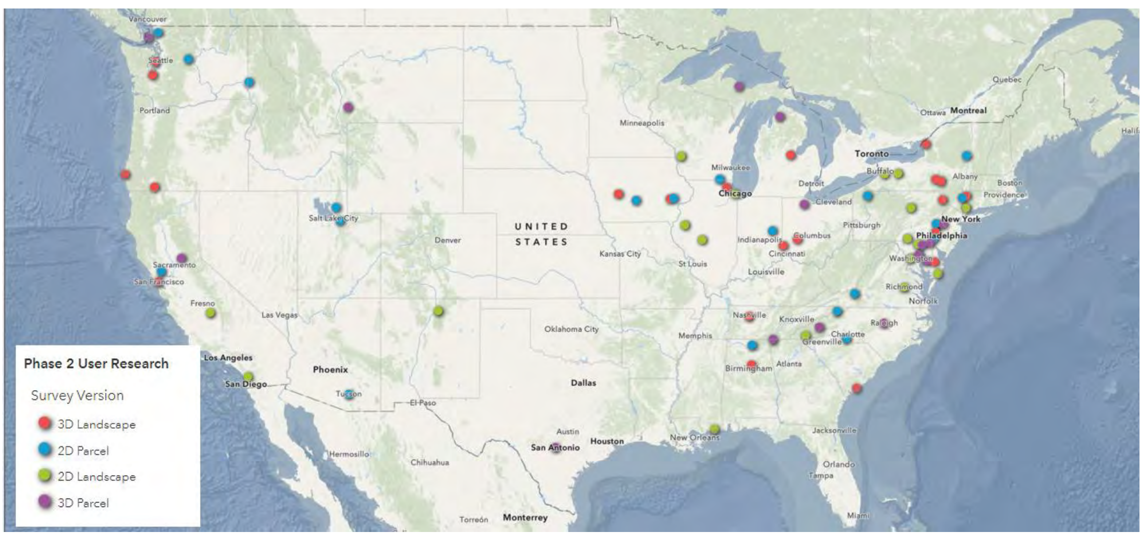


Figure 45. Location of participating land trust personnel by factor combinations.

Map Effectiveness

This research tested a series of null hypotheses associated with the effectiveness of 2D vs 3D maps for land trust communication purposes.

A two-way ANOVA was performed to analyze the effect of map dimensionality and map scale on map effectiveness, with the null hypothesis as follows:

H_0: Dimension (two-dimensional vs three dimensional) will have no significant effect on the effectiveness (as measured through the successful responses to task-based questions) of maps for communication purposes.

Simple main effects analysis showed that map dimensionality did not have a statistically significant effect on map effectiveness ($p = .65$).

H_0: Map Application Scale (landscape vs parcel) will have no significant effect on the effectiveness (as measured through the successful responses to task-based questions) of maps for communication purposes.

Simple main effects analysis showed that map scale did not have a statistically significant effect on map effectiveness ($p = .57$).

H_0: Dimension and map application scale interaction will have no significant effect on the effectiveness as measures through the successful completion of tasks) of maps for communication purposes

A two-way ANOVA revealed that there was not a statistically significant interaction between the effects of map dimensionality and map scale ($F(1, 92) = 1.29$, $p = .26$, *ns)*.

Descriptive Statistics. Descriptive statistics for the four factors of the ANOVA are shown in Table 5.

Table 5. Descriptive statistics for mean and standard deviation of each group of the ANOVA.

Descriptive Statistics

Dependent Variable: Mean Effectiveness Score

Dimension	Scale	Mean	Std. Deviation	N
2D	Landscape	.8472	.13011	22
	Parcel	.8604	.10985	25
	Total	.8542	.11861	47
3D	Landscape	.8633	.09469	29
	Parcel	.8228	.12855	20
	Total	.8468	.11034	49
Total	Landscape	.8563	.11043	51
	Parcel	.8437	.11864	45
	Total	.8504	.11392	96

ANOVA Results. Results of the Two-Way ANOVA are shown in Table 6.

Table 6. Results of ANOVA for Map Dimensionality x Map Scale and Map Effectiveness

Tests of Between-Subjects Effects

Dependent Variable: Mean Effectiveness Score

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	.023[a]	3	.008	.577	.632	.018
Intercept	67.772	1	67.772	5152.324	<.001	.982
Dimension	.003	1	.003	.208	.650	.002
Scale	.004	1	.004	.331	.567	.004
Dimension * Scale	.017	1	.017	1.291	.259	.014
Error	1.210	92	.013			
Total	70.660	96				
Corrected Total	1.233	95				

a. R Squared = .018 (Adjusted R Squared = -.014)

Map Usefulness

This research tested the following null hypotheses associated with the usefulness of 2D vs. 3D maps for land trust communication purposes:

H_0: There is no relationship between map dimensionality (two-dimensional and three-dimensional) and perceived map usefulness for land trust communication purposes.

A Chi-Square Test of Independence was performed to assess the relationship between map dimensionality (2D vs. 3D) and map usefulness.

There was a significant relationship between the two variables, X^2 (4, N = 480) = 34.58, $p < .001$. Three-dimensional maps were preferred to two-dimensional maps.

Descriptive statistics for the 2D and 3D map usefulness analysis are shown in Table 7 and Figure 50.

Table 7. Descriptive statistics for the map usefulness Chi-square test for Independence.

Dimension * Likert Crosstabulation

Count

		Likert					
		Fairly_good	Good	Poor	Very_good	Very_poor	Total
Dimension	2D	53	75	53	36	18	235
	3D	59	82	24	76	4	245
Total		112	157	77	112	22	480

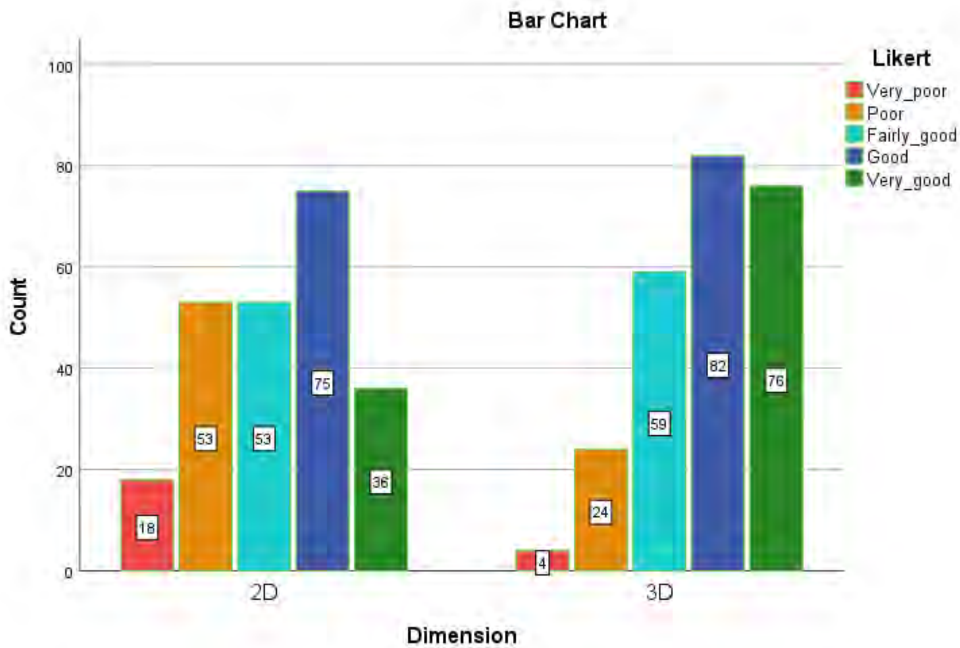


Figure 46. Distribution of Likert scale responses for map usefulness responses.

Results of the Chi-Square test are shown in Table 8.

Table 8. Results of Chi-Square test for 2D vs. 3D map usefulness analysis.

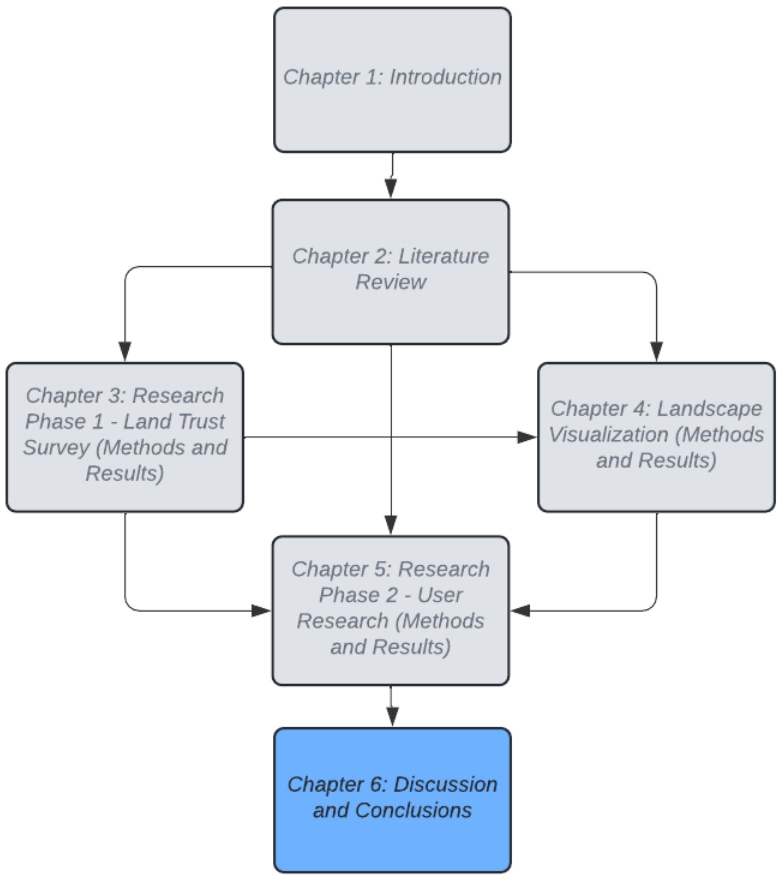
Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	34.557[a]	4	<.001
Likelihood Ratio	35.864	4	<.001
N of Valid Cases	480		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 10.77.

Chapter 6: Discussion and Conclusions

This purpose of this chapter is to provide a discussion of the results of Phase 2 of the research and recommendations.



The results of this study indicated that, based on a two-way ANOVA, there was no statistically significant difference in map effectiveness (1) between 2D maps and 3D scenes, (2) between landscape scale and parcel scale applications, and (3) when considering possible interaction effects between dimensionality and scale.

The results of the study did indicate that there was a statistically significant preference for 3D scenes over 2D maps when evaluating maps for usefulness in achieving communication objectives.

Reflections on Map and Scene Scale

This research evaluated map effectiveness at both a local (or parcel) scale and a regional (or landscape scale). This distinction, and the associated terminology, was intentional. The terms "parcel" and "landscape" were chosen, in part, because they may resonate with a broad and often non-technical audience characteristic of the land trust community. Those terms would likely also be understood by interested citizens in a land-use planning, farmland protection, or historic preservation context. Overall planning objectives, which may be communicated through local government plans and zoning ordinances, are often described at a landscape scale. Yet they are *implemented* (and hopefully achieved) through multiple public and private land-use decisions at the parcel scale (Croissant 2004).

The underlying principles associated with this description of scale, however, have both an ecological and perceptual association. From a land trust conservation values perspective, parcel and landscape are significant in conceptualizing the "*content*" and "*context*" of conservation projects. Increasingly the two perspectives are being considered together in environmental planning and decision-making.

To extend the concept further, there are now integrated mapping and analytical approaches to evaluate ecological or conservation values at both a local and regional scale. For example, Weber et al (2006) described an approach for the application of multi-scale ecological assessment to inform land conservation decisions. Svancara (2010) considered both ecological content and context in terms of the resiliency of National Parks to climate and land-use change. Similarly, there is a growing recognition that evaluating local scale restoration without considering the broader landscape context can impact the sustained viability of ecological restoration projects (Hobbs 2002).

Perceptually, conservation values are experienced and understood at different scales as well. A tourist enjoying a scenic overlook isn't experiencing the landscape in the same way as a tourist driving the countryside. Yet both are important in the context of a land trust striving to protect the conservation values of their focus or service area.

The significance of the "content vs. context" or "parcel vs. landscape" dichotomies is that these map or scene scales are both important to communicate conservation values – both in terms of map effectiveness and map usefulness. Choosing one scale as opposed to the other is driven by the communication purpose of the map or scene.

Reflections on Map Effectiveness

In this study, the map effectiveness score was based on the sum of correct answers to a series of questions based on specific map tasks. The tasks were derived from a task typology associated with typical map interactions. For purposes of this research, task success was aggregated into a composite score, but there is likely value in considering smaller subgroups of tasks and the users' performance associated with subgroups. For example, it is possible that a relationship could be uncovered by looking at subgroups of tasks based on the following.

Specific task interaction primitives (identify, compare, locate, distinguish, etc.).

It is possible that 2D or 3D could be better suited for a particular type of task, as opposed to an aggregate of all survey tasks. For example, tasks associated with the "identify" operation my score differently than tasks associated with the "distinguish" operation.

Elevation dependent tasks.

Three of the questions had a component that implied an understanding of the vertical dimension to produce a correct answer. For example, one question asked about the direction a waterway was flowing and another question asked to distinguish among points in the floodplain. Although there are visual clues on a 2D map that could assist in deriving the correct answer, it would be expected that a user would have a better chance at deriving the correct answer if they were exposed to a 3D representation of terrain.

Tasks associated with specific conservation values.

Not all conservation values are the same in terms of the expectations for the impacts of 3D. For example, "forest" is an image feature on 2D maps and is a 3D model in addition to the image feature in a 3D scene. Conversely, agriculture is a 2D feature on 2D maps and a 2D feature in a 3D scene (i.e., for purposes of this research it has no vertical dimension at the scale of the maps used). So, even though half of the participants completed 3D scene versions of the tests, the specific question related to agriculture was essentially rendered the same way in both depictions.

Reflections on Potential Independent Variable Interaction Effects

In the context of this research, it was distinctly possible (and anticipated) that there could be a relationship between the independent variables (i.e., "interaction effect"). Specifically, changing the scale of the experiment (from parcel to landscape) could have resulted in different map effectiveness in 2D as opposed to 3D. The rationale for a potentially different result is because the third dimension/verticality of scene features becomes more noticeable the closer the camera is to the features within the view. This draws from principles of 2.5 depth perception and applied cue theory. The closer you are to an object, the greater the impact of the vertical dimension on features within the view. If you are zoomed out to the point where the camera is thousands or even tens of thousands of feet away, the perceived verticality of a scene approaches zero. Therefore, one would expect that parcel-scale applications would have a greater linkage to 3D (either positive or negative) than landscape-scale applications.

The experimental design that was chosen for this research enabled an evaluation of any potential interaction effects between the independent variables. In this case, the specific interaction effect anticipated (and to be tested for) was that the effectiveness of a 2D map vs. 3D scene would be impacted by scale. In the examples included in the testing instrument, the default camera position for landscape applications is farther from the earth's surface than parcel applications.

Regarding the associated null hypothesis (i.e., that there was no relationship between scale and dimensionality), the between-subjects two-way ANOVA enabled a specific statistical test to characterize such an interaction. The results of the ANOVA, however, failed to find such a relationship.

Reflections on Map Usefulness

The map usefulness rating was based on a 5-point Likert scale for a series of ten questions relating to usefulness in achieving communication objectives. The Likert scale ratings ranged from very poor to very good. A nonparametric test for significance (Chi-Square test for Independence) was selected given that the individual Likert questions could be considered a nominal scale and the composite Likert scale could be considered nominal or ordinal.

Reflections on Experimental Design

Internal and External Validity

Efforts were made in the experimental design to control for both internal and external validity, but there were also known limitations based on experimental design and visualization development decisions.

Addressing internal validity. For purposes of this study, internal validity is concerned with whether the response to the user testing is related to the manipulation of the independent variables (dimensionality and scale) as opposed to other possible factors. For the map effectiveness part of the research, internal validity was addressed through the research design, careful consideration of the test population, and attention to the approach to rendering the visual elements that were varied between 2D maps and 3D scenes.

The selection a 2x2 between-subjects factorial design with random assignment of participants to the four test groups helped to maximize the internal validity of the map effectiveness study design. This was implemented by holding all aspects of the 2x2 factorial design constant except the independent variables being manipulated (dimensionality or scale).

In both the map effectiveness and map usefulness parts of the research, the test population was limited to land trust personnel as opposed to a more generic population (e.g., college students). This ensured that the participant population was representative of the target audience. Note that it was assumed that the best representation of the audiences of land trust communication products were the people responsible for communicating the message. In a perfect world it would be preferable to engage with the audience of the communication products itself.

The testing instrument limited the differences between 2D maps and 3D scenes to only those cartographic features with a vertical dimension (terrain, structures, and vegetation). All other cartographic design decisions, including choice of base map, were held constant between the 2D and 3D test questions. This helped to ensure that confounding factors were minimized.

Addressing external validity. External validity was addressed both in the overall research design as well as the specifics of the Phase 2 experimental design. Phase 1 of the research (survey of national land trusts) helped to confirm that the conservation values being visualized, and their corresponding communication purposes were, in fact, transferable to other land trust settings. This helped to validate the specific 2D map and 3D scene examples developed for Phase 2 of the research.

Also, drawing from the literature on previous map and geovisualization interaction studies, established map interaction task typologies were used to develop the specific map effectiveness questions for participants in Phase 2. This ensured that the specific tasks would be relatable to other land trust communication efforts.

Similarly, for the map usefulness questions, the information gathered in Phase 1 served to corroborate the communication context of questions used to determine preference of 2D vs 3D.

Finally, the comprehensive approach to reaching a representative/random sample of the entire population of United States land trusts and random assignment of test instruments to the four groups helped to ensure the transferability of results to other land trust settings.

Limitations or challenges to validity. Despite the care given to addressing validity issues in the experimental design, there are still some limitations worth noting.

Completing the Phase 2 survey on a mobile device was discouraged, but there was no attempt to prohibit a user from doing so. Studies have shown that 3D interaction may be more challenging on a mobile device and the success rate could have been impacted.

The selection of a Maryland site for the case study/survey questions may not be representative of other states and regions. The Upper Catoctin Creek watershed contains a mix of forest, agriculture, and rolling rural terrain. Other land trusts may focus their protection efforts on more or less diverse conditions, including land uses and terrain.

The spatial scale of the examples (focusing on catchments to represent "landscape" scale for example), may be less relevant in other parts of the U.S. Although many land trusts are concerned with watershed protection and many recognize hydrologic units as relevant to their protection efforts, other land trusts may define relevant landscapes using other criteria.

The selection of image-based maps for testing purposes (e.g., base map of aerial imagery) may limit the transferability of findings to other base map examples. Imagery is frequently used for base map purposes since it conveys a substantial amount of visual information without the need for extensive map labeling. Nonetheless, other base maps are used by land trusts and the results of this study do not necessarily translate to these situations.

Reflections on Landscape Visualization Methods

The method used to develop 3D scenes was derived from a specific workflow developed by Esri. There are other approaches for developing 3D models, and the technology continues to advance in terms of realism and interactivity. For example, an alternative approach is to render the 3D scene as a colorized LiDAR point cloud (See Figure 51). Other 3D modeling approaches (e.g., structure from motion, integrated mesh, holograms) could lead to different results in effectiveness scores and usefulness ratings.

Figure 47. Harpers Ferry, West Virginia 3D scene with vegetation rendered as colorized LiDAR point cloud.

In addition, alternative approaches to consuming 3D media may lead to the need to investigate effectiveness and usefulness through these other platforms. Virtual and augmented reality headsets provide other ways of consuming 3D content which could lead to different results. Finally, the increased integration of GIS and game engine technology (Heidelberg 2021) could impact effectiveness and usefulness evaluations as well.

Summary

Land trusts provide a valuable, although sometimes unheralded, service by providing complementary land conservation to Federal, state, and local government agencies throughout the United States. Technological advances in landscape visualization and 3D mapping have brought new capabilities and possibilities to land trusts to help communicate their important work. What has been lacking is an understanding of the role and limitations of these advancements in the context of real-world use cases. As 3D becomes more and more accessible, it will be increasingly important to understand when it is appropriate and when it is not. Computers have enabled easy access to 3D for information visualization (in addition to scientific visualization), but rarely does it serve a communication purpose unless the information being visualized has an inherent third dimension. Landscapes, and the natural and cultural elements they contain, certainly fall into that realm.

This research provided insights on the potential utility for using 2D and 3D maps to address the communication needs of land trusts. It draws from a better understanding of how land trusts use or could use interactive maps and scenes both internally to the land trust organization as well as externally to their varied audiences. Interactive 3D landscapes provide a more natural appearance because that is the way that humans experience landscapes. The subjective preference for 3D found in this research may reflect this characteristic.

This research also sets the stage for more detailed evaluation of the specific contexts where 3D might be warranted and refined to address unique use cases. This could include case studies that would focus on specific task types, different landscape settings, variations on cartographic representation of features (including alternative base maps), alternative media options for map consumption, and a closer examination of the consumers of maps themselves through the development of personas representative of various types of users.

The research also highlighted the need to better inform land trust personnel of the potential value and availability of 3D mapping. Although not specifically a product of the structured feedback on map usefulness, several participants expressed interest and enthusiasm for an expanded use of both interactive 2D web maps and 3D web scenes for their own organizations. This suggests a growing need for qualified digital cartographers with a land conservation interest who can not only develop useful products using existing technology, but also stay current with technological advancements.

Future Directions and Impacts to the Field

This research focused on the potential use of interactive 3D landscapes in the context of land conservation – specifically land trusts with conservation objectives relevant at both parcel and landscape scales. There are commonalities associated with this specific research context and other applied science and landscape design disciplines. This section provides an overview of how some of the methods and lessons learned may be extended to other disciplines. Given the preference for 3D scenes over 2D maps for the variety of communication purposes found in this research, these disciplines may also benefit from practitioners from these fields learning how to address communication purposes specific to their disciplines. Examples include:

Watershed Restoration - Watershed restoration also incorporates ecological processes operating at multiple spatial scales. In some cases, restoration projects not only provide benefits to local waterways but may extend beyond a project or parcel boundary to generate benefits to an entire watershed. To the extent that restoration practices and their anticipated benefits can be mapped, landscape visualization has the potential to help communicate potential future conditions (post-restoration).

Landscape Design - Landscape ecology is concerned with the pattern of elements on the landscape and the ecological processes associated with these elements at multiple scales. A relatively new discipline, its initial focus was primarily academic in nature but has since evolved into a more practical discipline with the evolution of landscape architecture (Drumstad et al 1996) and the emergence of geodesign (Steinitz 2012 and Perkl 2016). Interactive landscape visualization will have an expanded role in both academic and applied settings to communicate theoretical and actual place-based impacts of different landscape architecture and geodesign proposals, particularly where interaction can enhance the experience.

Recreational Planning - Recreational planning can leverage landscape visualization to provide a more realistic perceptual experience than is afforded from 2D maps alone. Examples include not only the aforementioned scenic viewsheds and scenic roadway experiences, but also the potential for immersive experiences along recreational trails.

Local Government Planning - Perhaps the greatest area of impact is in local comprehensive planning and the ability to evaluate future conditions under various planning and development scenarios. As noted earlier, this use case is well established in urban planning and design. Conversely, the emphasis of this research has been on rural land trust conservation applications. However, the utility of landscape visualization extends well beyond that specific use case and its associated audience. Rural areas face unique challenges in terms of preserving resource-based industry, ensuring socioeconomic sustainability, and transportation and infrastructure planning and management. The preference for 3D demonstrated in this research could be translated to these other application areas, thereby leading to a more engaged and participatory citizenry.

Forestry – Forestry has utilized landscape visualization dating at least since the 1970's. The Visual Management System (Bacon 1979), and the subsequent Scenery Management System (Bedwell 2004), set the stage for leveraging 3D forest models in the assessment of impacts to scenic resources resulting from forest management. It has shown to be particularly effective in communicating the visual impact of alternative forest management and harvesting scenarios.

Communicating Climate Change - Finally, landscape visualization may serve a particularly important role in communicating the effects of climate change. As a wicked environmental problem facing society, there are now numerous studies suggesting that climate change becomes "real" when its impacts are felt locally by a given audience. (see, for example, Sheppard 2012, Armstrong et al 2018, Spence & Pigeon 2010, Degeling & Koolin 2022). Visualizing impacts in a local context enhances understanding – especially when those impacts demonstrate the consequences of climate change with and without intervention activities. As a result, landscape visualization representing real-world locations that resonate with place-based audiences may ultimately serve a major role in convincing decision-makers to take action.

This research extends commonly used technological tools and approaches to a different setting beyond what has been thoroughly investigated in the past – rural landscape visualization applications and land conservation communication. It also established a paradigm for communicating "content" and "context" considerations in landscape visualization applications that could be extended to other disciplines with similar needs or requirements.

Although the research did not find a relationship between map effectiveness and the independent variables of scale or dimensionality, it did show that interactive 3D scenes have a role in enhanced communication and are, in fact, preferred by audiences charged with developing and promoting maps among land trusts. As such, these scenes can be important to develop support or buy-in for land conservation proposals and to communicate potential threats to or vulnerability of conservation values important to land trusts. Specifically, this research also sets the stage to leverage landscape modeling to visualize future conditions under a wide range of natural and human-induced change scenarios.

These findings have relevance to multiple audiences. From the academic perspective, this includes educating GIS and design professionals on the benefits and implementation options for 3D landscape modeling and visualization. Three-dimensional GIS is now in the toolbox of mapping professionals and design practitioners. As more and more examples appear, there will be a need to meet the increased demand for 3D mapping and web cartographers. At a minimum, we can anticipate land trusts seeking qualified contractors to help develop communication products that land trust stakeholders find informing and engaging.

Government agencies sometimes lag in their adoption of 3D mapping capabilities. This project demonstrated the potential for leveraging landscape visualization in the context of one activity that could extend the specific use case of land conservation activities of land trusts to the public sector. There are similar communication needs for state and local governments to convince private citizens and stakeholders of the value of public investments in land conservation. Visualizing alternative futures, without and without public investment strategies, is well suited to landscape visualization.

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Appendix A: Landscape Characteristics of Upper Catoctin Creek Study Area (Stroud Water Research Center 2022)

Land Cover

Type	NLCD Code	Area (mi²)	Coverage (%)	Active River Area (mi²)
Open Water	11	0.03	0.09	0
Perennial Ice/Snow	12	0	0	0
Developed, Open Space	21	2.04	6.09	0.38
Developed, Low Intensity	22	0.44	1.31	0.08
Developed, Medium Intensity	23	0.07	0.2	0.02
Developed, High Intensity	24	0	0.01	0
Barren Land (Rock/Sand/Clay)	31	0.03	0.08	0
Deciduous Forest	41	18.44	55.01	2.56
Evergreen Forest	42	0.18	0.54	0.03
Mixed Forest	43	2.24	6.67	0.41
Shrub/Scrub	52	0.11	0.34	0.01
Grassland/Herbaceous	71	0.19	0.56	0.03
Pasture/Hay	81	7.7	22.96	1.46
Cultivated Crops	82	1.96	5.84	0.43
Woody Wetlands	90	0.08	0.23	0.03
Emergent Herbaceous Wetlands	95	0.02	0.05	0
Total		33.52	100	5.45

Landform Characteristics

	Elevation (ft)	Slope (%)
Average	1,205.10	12.4
Minimum	559.9	0
Maximum	1,895.00	53.2

Appendix B: Tree Species of the Blue Ridge Physiographic Province

Section M 221D – Blue Ridge Mountains

northern red oak
black oak
white oak
chestnut oaks
pitch pine
white pine
yellow poplar
red maple
northern red oak
birch

Source: McNab, W. H., Cleland, D. T., Freeouf, J. A., Keys, J. E., Nowacki, G. J., & Carpenter, C. (2007). Description of ecological subregions: sections of the conterminous United States. General Technical Report WO-76B, 76, 1-82.

Appendix C: Detailed Landscape Modeling Methods

Modified and Augmented from Esri 3D Basemap Solution Task Workflow (Esri 2021a)

1. Study area GIS data preparation
    a. Download National Watershed boundary dataset
    b. Select Upper Catoctin Creek HUC 12 boundary to define study area
    c. Download National Hydrography Dataset (v2) area feature data
    d. Select NHD Catchments within Upper Catoctin Creek HUC 12
2. LiDAR access and preparation
    a. Access Maryland GIS Pred-defined LiDAR point clouds from Maryland GIS Data Catalog (https://imap.maryland.gov/Pages/lidar-download-files.aspx)
    b. Identify appropriate Block(s) corresponding to Study Area
        i. Catoctin Creek Study Area is Frederick County Block 10
    c. Download LAZ files to appropriate directory
    d. Using LASZIP, decompress LAZ files to LAS format.
3. Parcel and building data preprocessing
    a. Access and download Maryland Property Data (Parcel Points) from Maryland GIS Data Catalog (https://data.imap.maryland.gov/datasets/maryland::maryland-property-data-parcel-points/about)
    b. Access and download parcel boundaries from Frederick County GIS (https://gis-fcgmd.opendata.arcgis.com/datasets/fcgmd::parcels/about)
    c. Perform spatial join of Property Data (point) attributes to Parcel (polygons) boundaries (yr_built attribute)
    d. Access and download Frederick County building footprint data (https://gis-fcgmd.opendata.arcgis.com/datasets/fcgmd::buildings/about) and edge-of-pavement (https://gis-fcgmd.opendata.arcgis.com/datasets/fcgmd::edge-of-pavement/about)
    e. Perform spatial join of joined Parcel data to building footprint layer (yr_built attribute) – end product is a building footprint layer with yr-built and otter attributes.
    f. Perform spatial join of NHD Catchment FeatureID to building footprint layer. This modified building footprint layer (with catchment and parcel attributes) is used as input to the following 3D basemap processing steps.
4. ArcGIS Pro
    a. Install 3D Basemap Solution
    b. Select catchments of interest
    c. Identify LAS tiles overlapping catchment(s)
    d. Add LAS files to ArcGIS Pro project

e. Create LAS dataset
f. Publish Ground elevation surface
    i. Extract elevation surfaces from LAS dataset (DTM, DSM, nDSM)
        1. Add building footprints to Scene
        2. Modify ground elevation surface around buildings (DTM_mod)
    ii. Publish ground elevation surface to AGOL
        1. Set elevation to meters
        2. Reproject DTM_Meters to Web Mercator Auxiliary Sphere
        3. Add the projected elevation surface to the ground in ArcGIS Pro
        4. Publish elevation surface layer
g. Publish Buildings
    i. If necessary, extract building footprints from LiDAR
    ii. Split building footprints into parts to account for complex roofs
    iii. Create LOD2 buildings from building footprints
    iv. Fuse building parts resulting from split footprints
    v. Convert to multipatch feature class
    vi. Add textures to buildings (if necessary)
    vii. Publish buildings layer to AGOL
h. Publish Trees
    i. LiDAR processing
        1. Extract tree points from LiDAR using surface analysis tools
        2. Define LiDAR class codes representing vegetation (or use 1 if undefined)
        3. Enter building footprints to distinguish vegetation from buildings
        4. Establish buffer around buildings to prevent vegetation/structure z-fighting
        5. Set minimum and maximum canopy heights
        6. Specify DTM upon which to “grow” trees
    ii. Assign species attributes to tree points
        1. Add species_number field to house random number
        2. Generate random number to populate species_number field
        3. Add species field to house species name
        4. Assign species name based on species prevalence in lookup table included in Appendix X.
        5. Add trees as preset to scene
    iii. Supplement LiDAR trees with randomly generated trees (to increase forest stand density)

1. Extract forest land cover polygon class for study area
2. Generate random points within extracted forest polygon
3. Add species_number field to house random number
4. Generate random number to populate species_number field
5. Add species field to house species name
6. Assign species name based on species prevalence in lookup table included in Appendix X.
7. Add trees as preset to scene
8. Publish tree layers to AGOL

i. Publish ancillary GIS data to AGOL - for this research project, the following ancillary data was published as 2D overlays for incorporation into web maps and web scenes
    1. Building footprints (Frederick County GIS)
    2. Edge of pavement (Frederick County GIS)
    3. Floodplain (Frederick County GIS)
    4. Land cover (Chesapeake Conservancy 2013)
    5. Parcel boundaries (Frederick County GIS)
    6. State designated scenic roads (Maryland GIS Data Catalog)
    7. Building attributes – including age of structure (Maryland GIS Data Catalog)
    8. Viewshed vantage points
    9. Catoctin Creek study area boundary (extracted from National Watershed Boundary dataset)
    10. Catoctin Creek catchment boundaries (extracted from National Hydrography Dataset Plus v. 2.1)
    11. Catoctin Creek Streams (extracted from National Hydrography Dataset Plus v. 2.1)

ii. Clip data to study area

iii. Project data to Web Mercator Auxiliary Sphere

iv. Publish or upload data to AGOL

5. ArcGIS Online (AGOL)
    a. Web Maps (2D) and Web Scenes
        i. Add NAIP imagery base map
        ii. Add parcel boundaries
        iii. Add catchment boundaries
        iv. Add edge of pavement
    b. Web Maps (2D)
        i. Add building footprints
    c. Web Scenes (3D)
        i. Add building multipatches

1. Render as LOD 2 buildings

ii. Add vegetation presets

1. Render based on species field

6. ArcGIS Story Maps
    a. Create six individual story maps - one for each specific location associated with a Phase 2 survey question
        i. 2D landscape (Questions 1-6)
        ii. 2D parcel (Questions 1-6)
        iii. 3D landscape (Questions 1-6)
        iv. 3D parcel (Questions 1-6)
    b. Combine individual story maps into four story map collections
        i. 2D landscape
        ii. 2D parcel
        iii. 3D landscape
        iv. 3D parcel

Appendix D: Story Map Collections

These story map collections became the test materials corresponding to the four distinct Phase 2 survey instruments. These story map collections are accessible at:

2D Landscape -
https://storymaps.arcgis.com/collections/4f9616a019fe417da53c508006ae0e67

2D Parcel -
https://storymaps.arcgis.com/collections/aaf0e4f3baa24e6c808ab7ea1c018b13

3D Landscape -
https://storymaps.arcgis.com/collections/f1b411d144034c72a44b23daa2060475

3D Parcel -
https://storymaps.arcgis.com/collections/fe10edda49bc433bab20da10c13ab6c0

Appendix E: Map Effectiveness – Survey Task Typology

Effectiveness Questions	Task Type
Question 1 - Which parcel contains a higher percentage of forest/trees/shrubs?	Compare, Distinguish
Question 2 - Which parcel contains a higher percentage of impervious surfaces?	Compare, Distinguish
Question 3 - Which parcel would sequester more carbon on a per-acre basis?	Compare, Distinguish, Associate
Question 4 - Identify the corresponding land cover types at locations A, B, C, D and E	Identify
Question 5 - In which direction is the stream flowing?	Associate
Question 6 - Within the boundary of the parcel, how many structures would be impacted by a 100-year flood?	Locate, Associate
Question 7 - There are four points located on the map (1, 2, 3, and 4). Three of the four are located within the same land cover type. Which point has a different land cover type?	Distinguish, Categorize
Question 8 - Which point is at the highest elevation?	Compare, Distinguish
Question 9 - Which point is at the lowest elevation?	Compare, Distinguish
Question 10 - Of the four proposed project locations (1, 2, 3, or 4), which two are likely to be visible from the scenic road?	Compare, Distinguish, Associate
Question 11 - Which proposed project location is closest to the scenic road?	Compare, Distinguish
Question 12 - Which proposed project location is farthest from the scenic road?	Compare, Distinguish
Question 13 - How many structures within the boundary of the parcel were built prior to 1900?	Identify, Categorize

Appendix F: Map Effectiveness – Question Responses

This appendix includes summaries of the responses to individual map effectiveness questions.

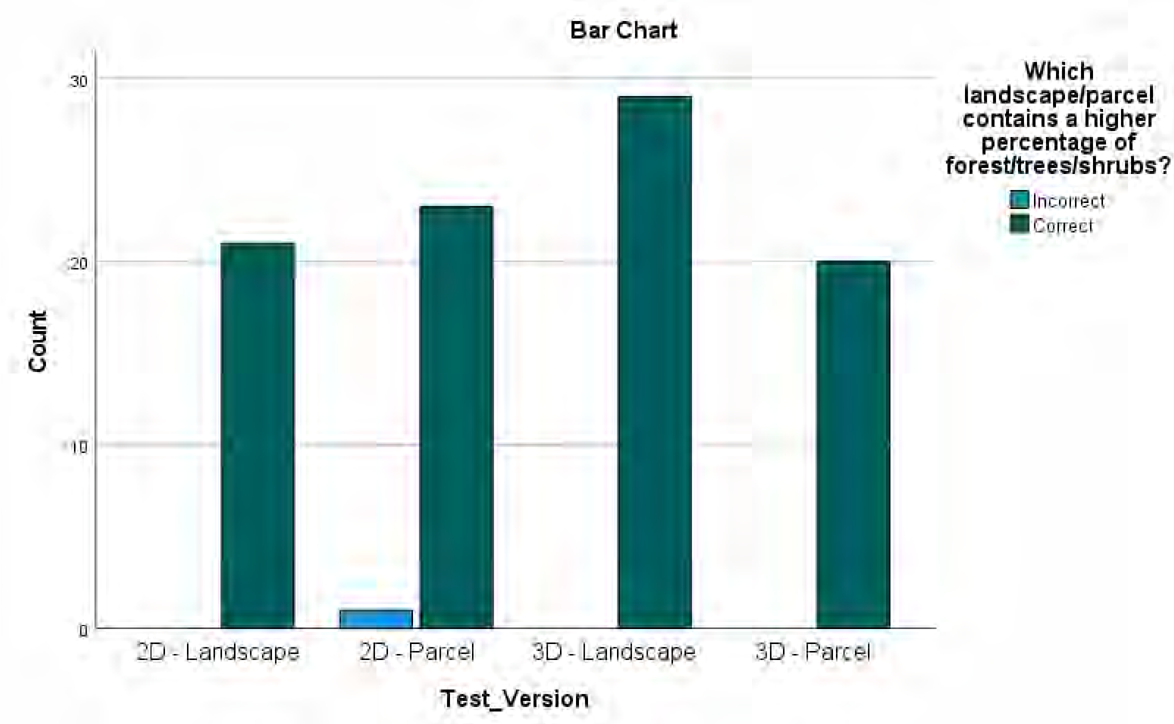
appendix includes summaries of the responses to individual map effectiveness questions.

Test_Version * Which landscape/parcel contains a higher percentage of forest/trees/shrubs? Crosstabulation

Count

		Which landscape/parcel contains a higher percentage of forest/trees/shrubs?		
		Incorrect	Correct	Total
Test_Version	2D - Landscape	0_a	21_a	21
	2D - Parcel	1_a	23_a	24
	3D - Landscape	0_a	29_a	29
	3D - Parcel	0_a	20_a	20
Total		1	93	94

Each subscript letter denotes a subset of Which landscape/parcel contains a higher percentage of forest/trees/shrubs? categories whose column proportions do not differ significantly from each other at the .05 level.

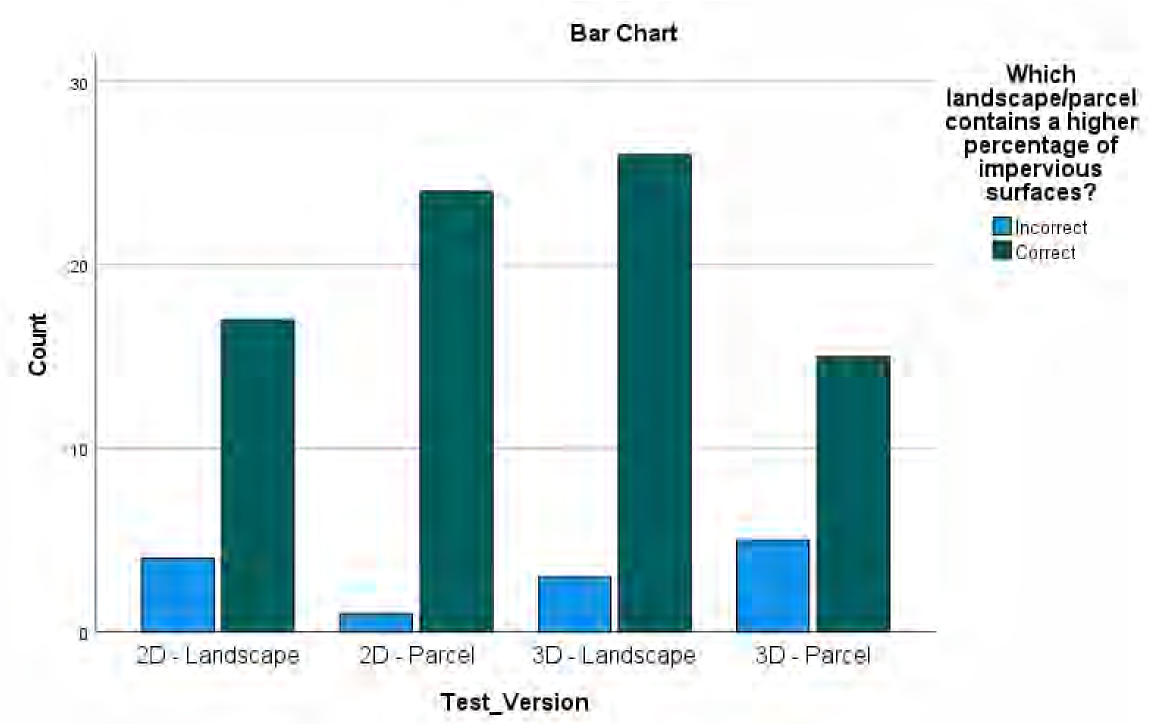

Bar Chart
Count
30
20
10
0
2D - Landscape
2D - Parcel
3D - Landscape
3D - Parcel
Test_Version
Which landscape/parcel contains a higher percentage of forest/trees/shrubs?
Incorrect
Correct

Test_Version * Which landscape/parcel contains a higher percentage of impervious surfaces? Crosstabulation

Count

		Which landscape/parcel contains a higher percentage of impervious surfaces?		
		Incorrect	Correct	Total
Test_Version	2D - Landscape	4_a	17_a	21
	2D - Parcel	1_a	24_a	25
	3D - Landscape	3_a	26_a	29
	3D - Parcel	5_a	15_a	20
Total		13	82	95

Each subscript letter denotes a subset of Which landscape/parcel contains a higher percentage of impervious surfaces? categories whose column proportions do not differ significantly from each other at the .05 level.

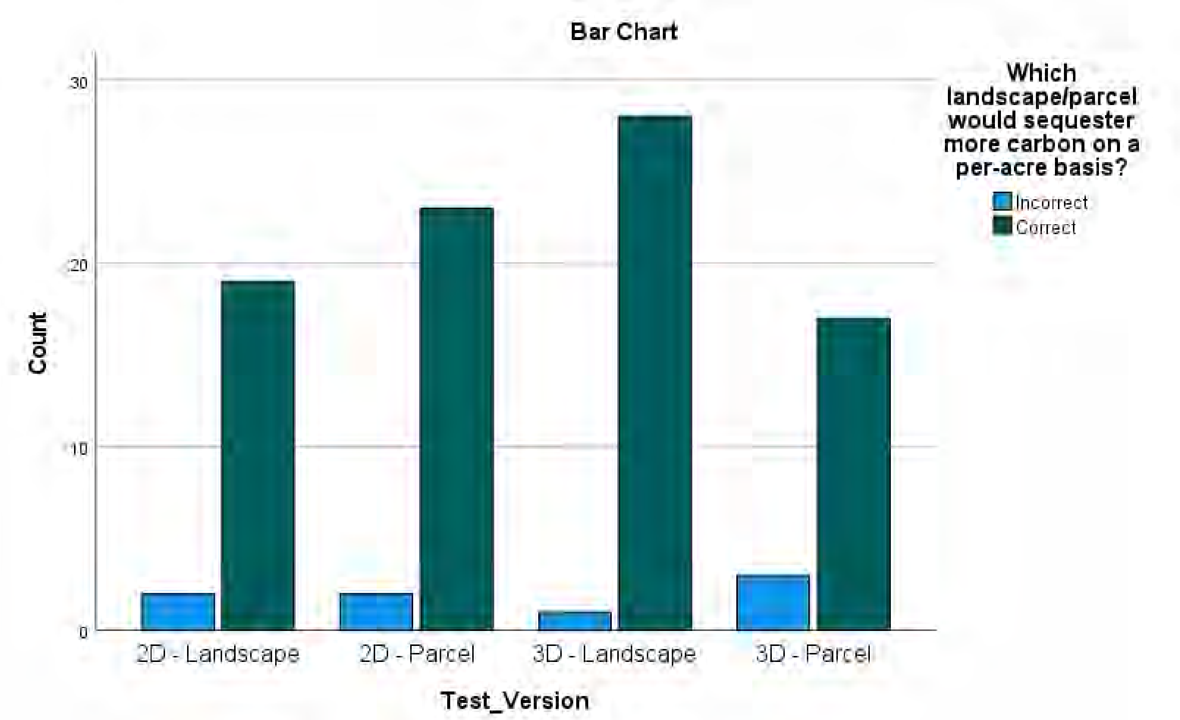


Test_Version * Which landscape/parcel would sequester more carbon on a per-acre basis? Crosstabulation

Count

		Which landscape/parcel would sequester more carbon on a per-acre basis?		
		Incorrect	Correct	Total
Test_Version	2D - Landscape	2_a	19_a	21
	2D - Parcel	2_a	23_a	25
	3D - Landscape	1_a	28_a	29
	3D - Parcel	3_a	17_a	20
Total		8	87	95

Each subscript letter denotes a subset of Which landscape/parcel would sequester more carbon on a per-acre basis? categories whose column proportions do not differ significantly from each other at the .05 level.

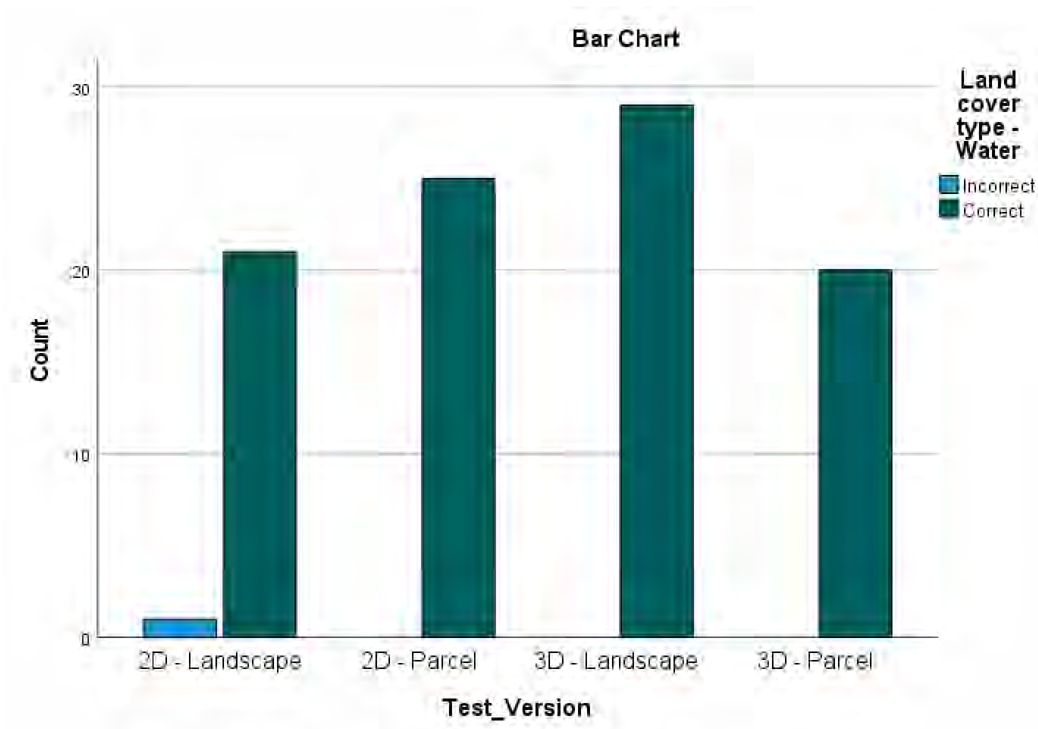


Test_Version * Land cover type - Water Crosstabulation

Count

		Land cover type - Water		
		Incorrect	Correct	Total
Test_Version	2D - Landscape	1_a	21_a	22
	2D - Parcel	0_a	25_a	25
	3D - Landscape	0_a	29_a	29
	3D - Parcel	0_a	20_a	20
Total		1	95	96

Each subscript letter denotes a subset of Land cover type - Water categories whose column proportions do not differ significantly from each other at the .05 level.

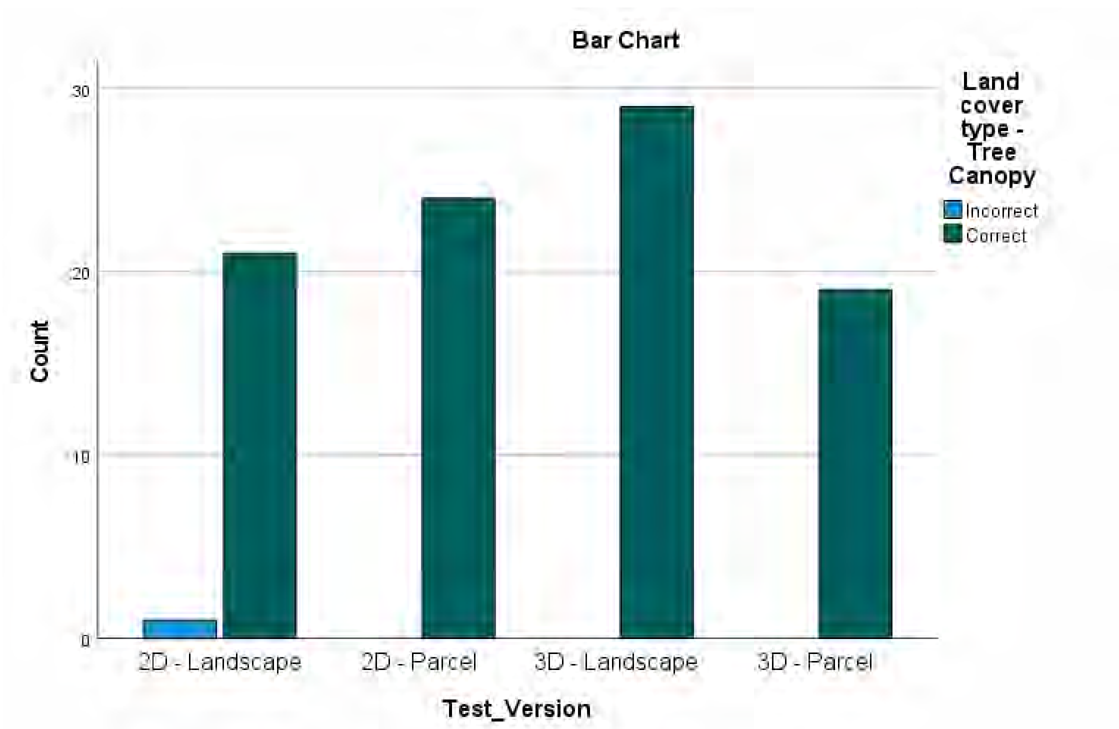


Test_Version * Land cover type - Tree Canopy Crosstabulation

Count

		Land cover type - Tree Canopy		
		Incorrect	Correct	Total
Test_Version	2D - Landscape	1_a	21_a	22
	2D - Parcel	0_a	24_a	24
	3D - Landscape	0_a	29_a	29
	3D - Parcel	0_a	19_a	19
Total		1	93	94

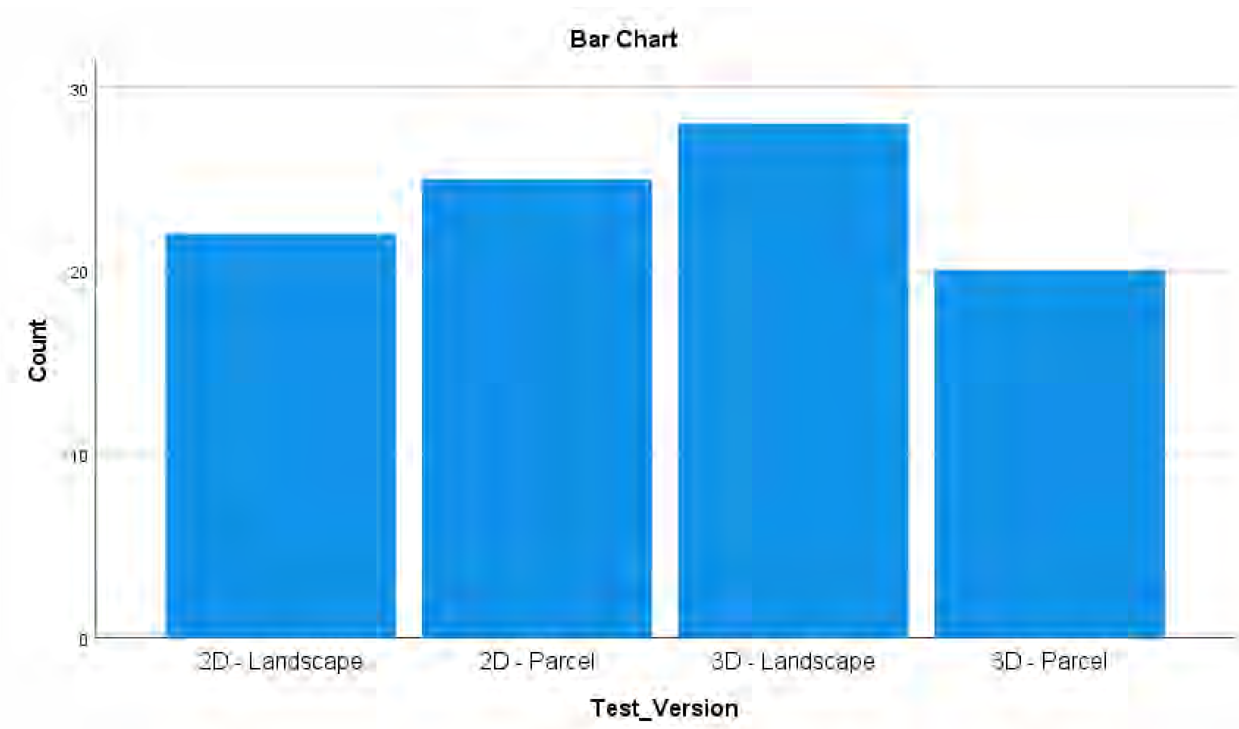
Each subscript letter denotes a subset of Land cover type - Tree Canopy categories whose column proportions do not differ significantly from each other at the .05 level.



Test_Version * Land cover type - Low Vegetation Crosstabulation

Count

		Land cover type - Low Vegetation	Total
		Correct	
Test_Version	2D - Landscape	22	22
	2D - Parcel	25	25
	3D - Landscape	28	28
	3D - Parcel	20	20
Total		95	95

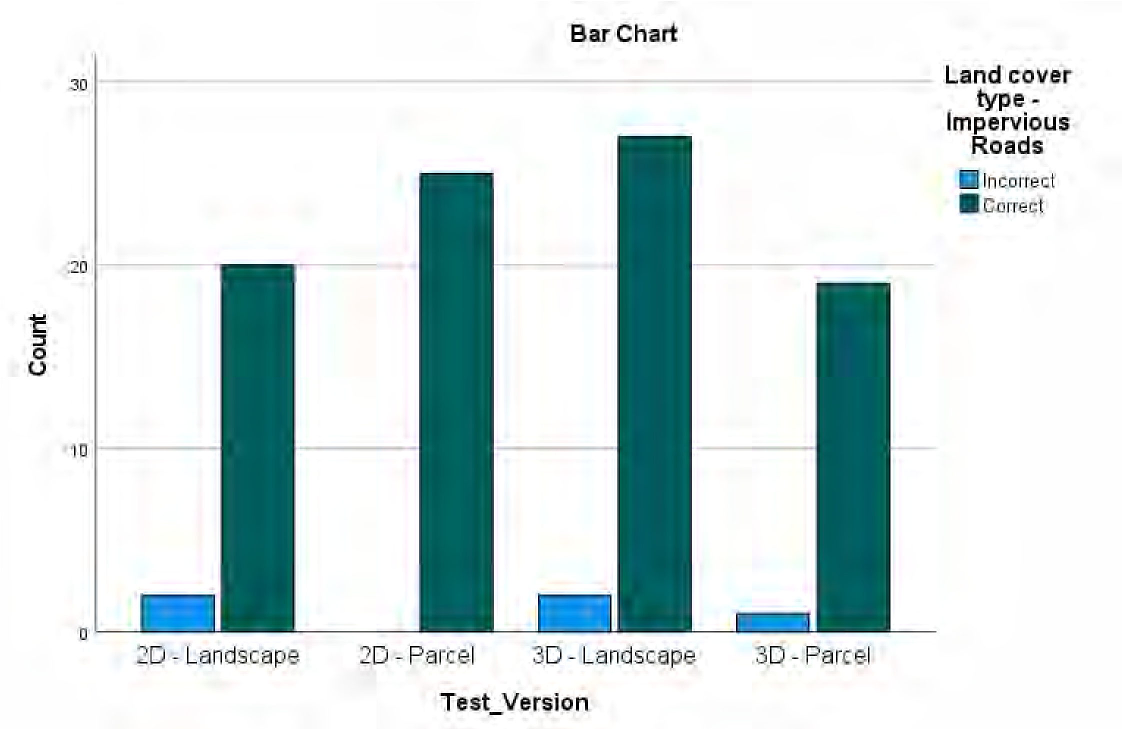


Test_Version * Land cover type - Impervious Roads Crosstabulation

Count

		Land cover type - Impervious Roads		
		Incorrect	Correct	Total
Test_Version	2D - Landscape	2_a	20_a	22
	2D - Parcel	0_a	25_a	25
	3D - Landscape	2_a	27_a	29
	3D - Parcel	1_a	19_a	20
Total		5	91	96

Each subscript letter denotes a subset of Land cover type - Impervious Roads categories whose column proportions do not differ significantly from each other at the .05 level.

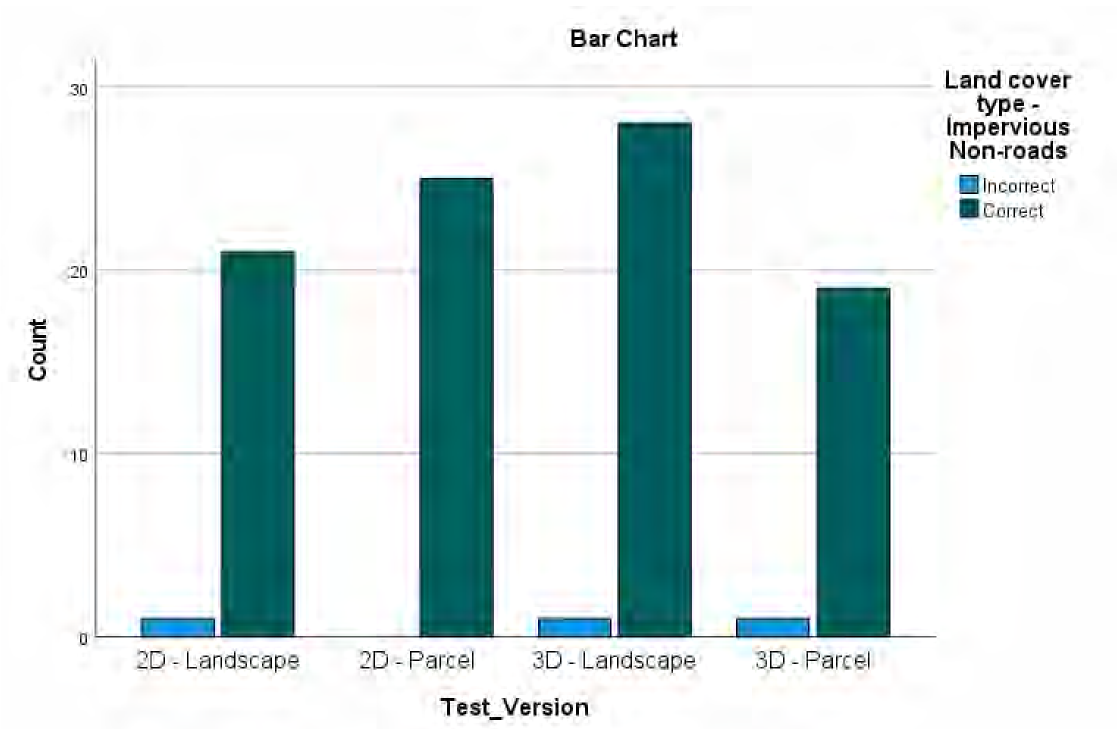


Test_Version * Land cover type - Impervious Non-roads Crosstabulation

Count

		Land cover type - Impervious Non-roads		
		Incorrect	Correct	Total
Test_Version	2D - Landscape	1_a	21_a	22
	2D - Parcel	0_a	25_a	25
	3D - Landscape	1_a	28_a	29
	3D - Parcel	1_a	19_a	20
Total		3	93	96

Each subscript letter denotes a subset of Land cover type - Impervious Non-roads categories whose column proportions do not differ significantly from each other at the .05 level.

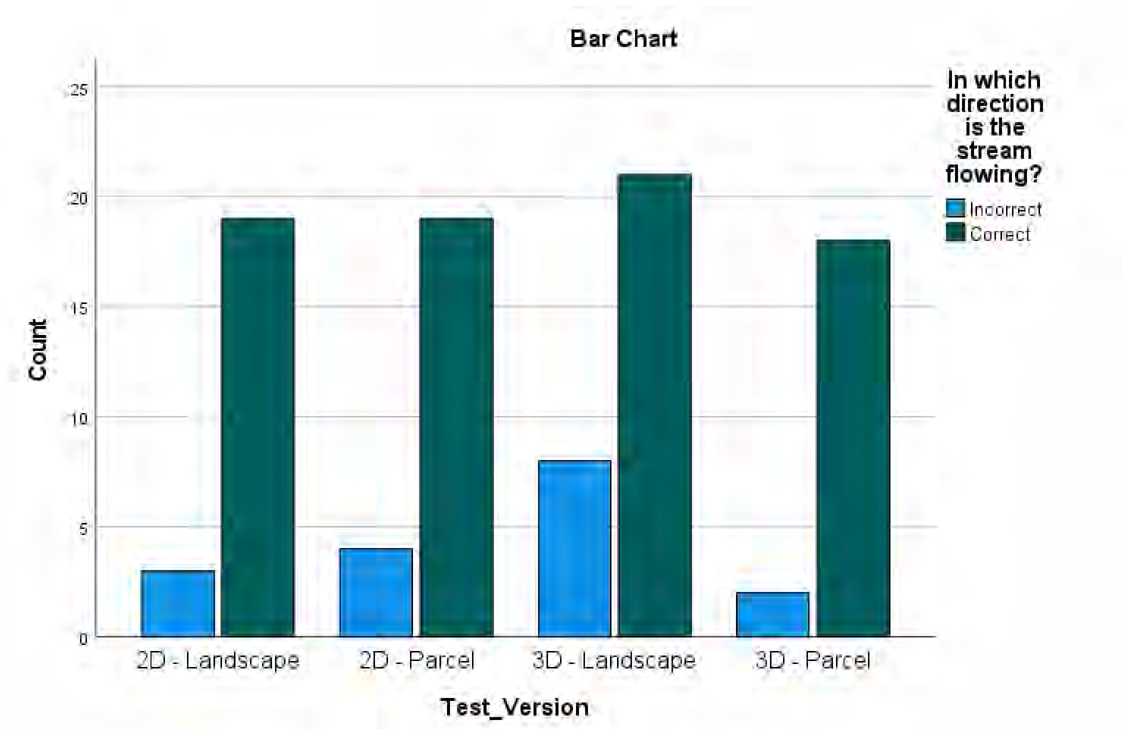


Test_Version * In which direction is the stream flowing? Crosstabulation

Count

		In which direction is the stream flowing?		
		Incorrect	Correct	Total
Test_Version	2D - Landscape	3_a	19_a	22
	2D - Parcel	4_a	19_a	23
	3D - Landscape	8_a	21_a	29
	3D - Parcel	2_a	18_a	20
Total		17	77	94

Each subscript letter denotes a subset of In which direction is the stream flowing? categories whose column proportions do not differ significantly from each other at the .05 level.

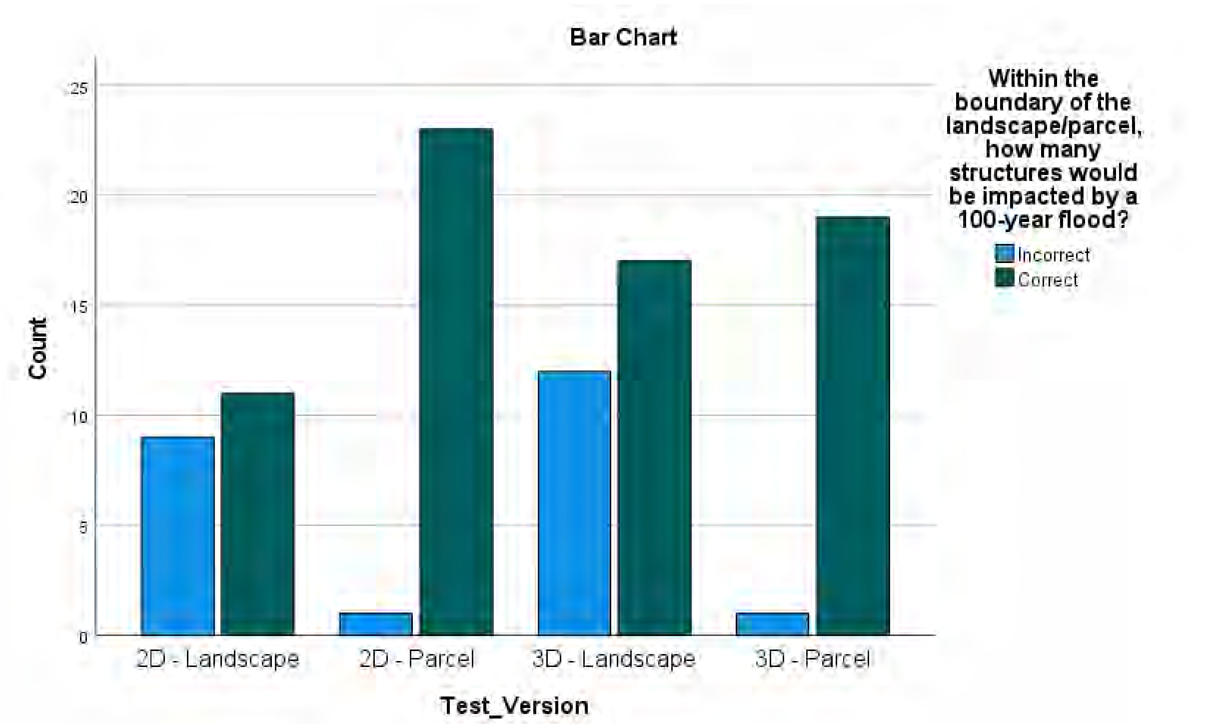


Test_Version * Within the boundary of the landscape/parcel, how many structures would be impacted by a 100-year flood? Crosstabulation

Count

		Within the boundary of the landscape/parcel, how many structures would be impacted by a 100-year flood?		
		Incorrect	Correct	Total
Test_Version	2D - Landscape	9a	11b	20
	2D - Parcel	1a	23b	24
	3D - Landscape	12a	17b	29
	3D - Parcel	1a	19b	20
Total		23	70	93

Each subscript letter denotes a subset of Within the boundary of the landscape/parcel, how many structures would be impacted by a 100-year flood? categories whose column proportions do not differ significantly from each other at the .05 level.

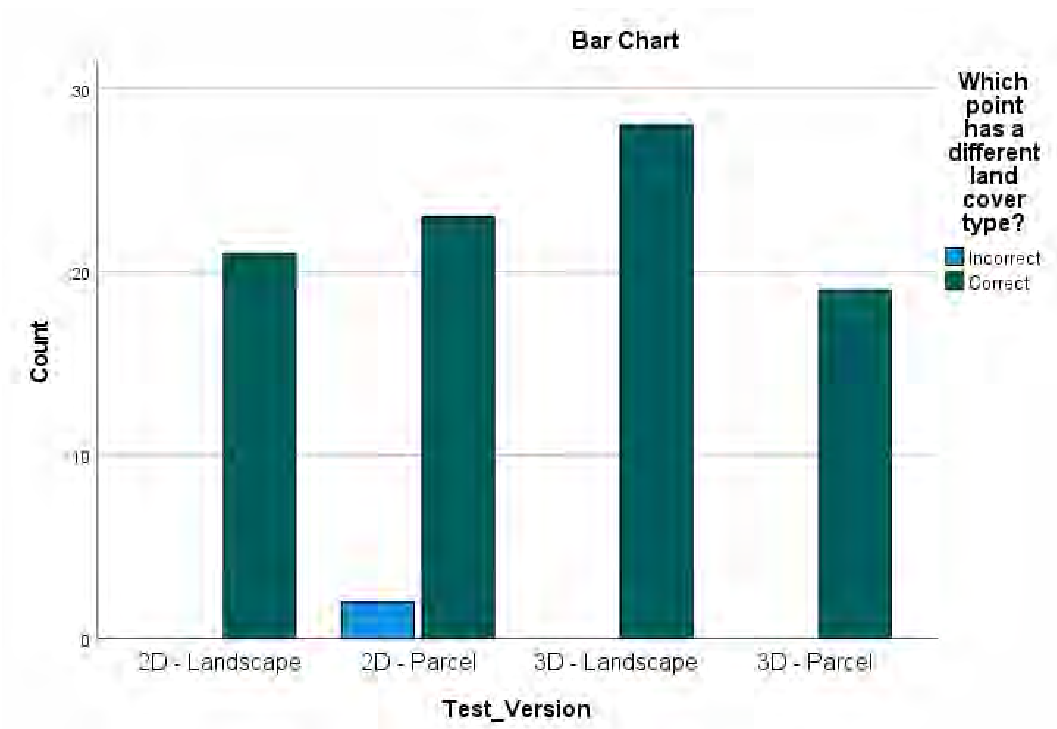


Test_Version * Which point has a different land cover type? Crosstabulation

Count

		Which point has a different land cover type?		
		Incorrect	Correct	Total
Test_Version	2D - Landscape	0_a	21_a	21
	2D - Parcel	2_a	23_b	25
	3D - Landscape	0_a	28_a	28
	3D - Parcel	0_a	19_a	19
Total		2	91	93

Each subscript letter denotes a subset of Which point has a different land cover type? categories whose column proportions do not differ significantly from each other at the .05 level.

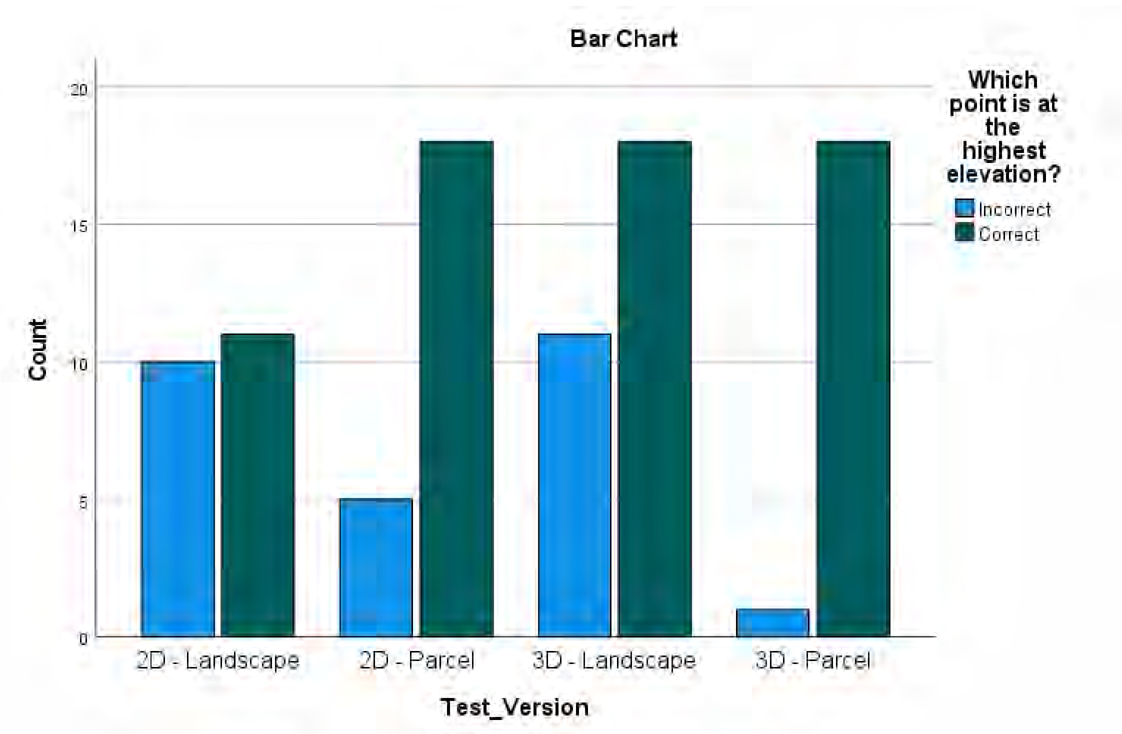


Test_Version * Which point is at the highest elevation? Crosstabulation

Count

		Which point is at the highest elevation?		
		Incorrect	Correct	Total
Test_Version	2D - Landscape	10_a	11_b	21
	2D - Parcel	5_a	18_a	23
	3D - Landscape	11_a	18_a	29
	3D - Parcel	1_a	18_b	19
Total		27	65	92

Each subscript letter denotes a subset of Which point is at the highest elevation? categories whose column proportions do not differ significantly from each other at the .05 level.

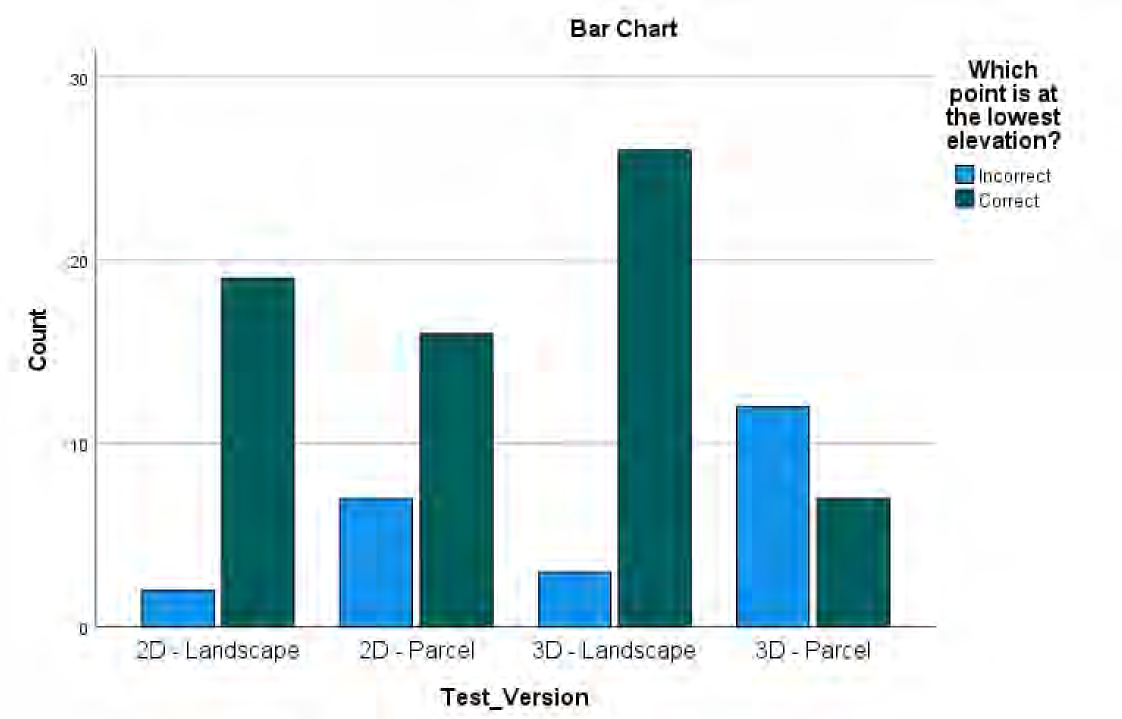


Test_Version * Which point is at the lowest elevation? Crosstabulation

Count

		Which point is at the lowest elevation?		
		Incorrect	Correct	Total
Test_Version	2D - Landscape	2_a	19_b	21
	2D - Parcel	7_a	16_a	23
	3D - Landscape	3_a	26_b	29
	3D - Parcel	12_a	7_b	19
Total		24	68	92

Each subscript letter denotes a subset of Which point is at the lowest elevation? categories whose column proportions do not differ significantly from each other at the .05 level.

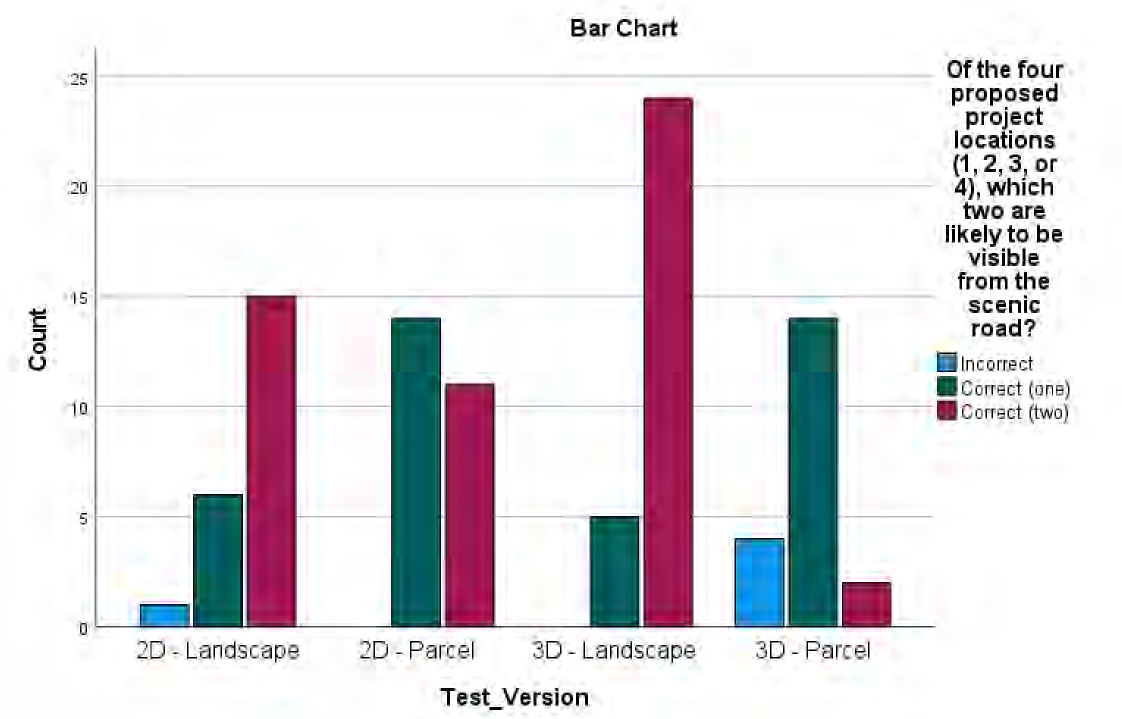


Test_Version * Of the four proposed project locations (1, 2, 3, or 4), which two are likely to be visible from the scenic road? Crosstabulation

Count

		Of the four proposed project locations (1, 2, 3, or 4), which two are likely to be visible from the scenic road?			
		Incorrect	Correct (one)	Correct (two)	Total
Test_Version	2D - Landscape	1_a	6_a	15_a	22
	2D - Parcel	0_a	14_a	11_a	25
	3D - Landscape	0_a	5_a	24_b	29
	3D - Parcel	4_a	14_a	2_b	20
Total		5	39	52	96

Each subscript letter denotes a subset of Of the four proposed project locations (1, 2, 3, or 4), which two are likely to be visible from the scenic road? categories whose column proportions do not differ significantly from each other at the .05 level.

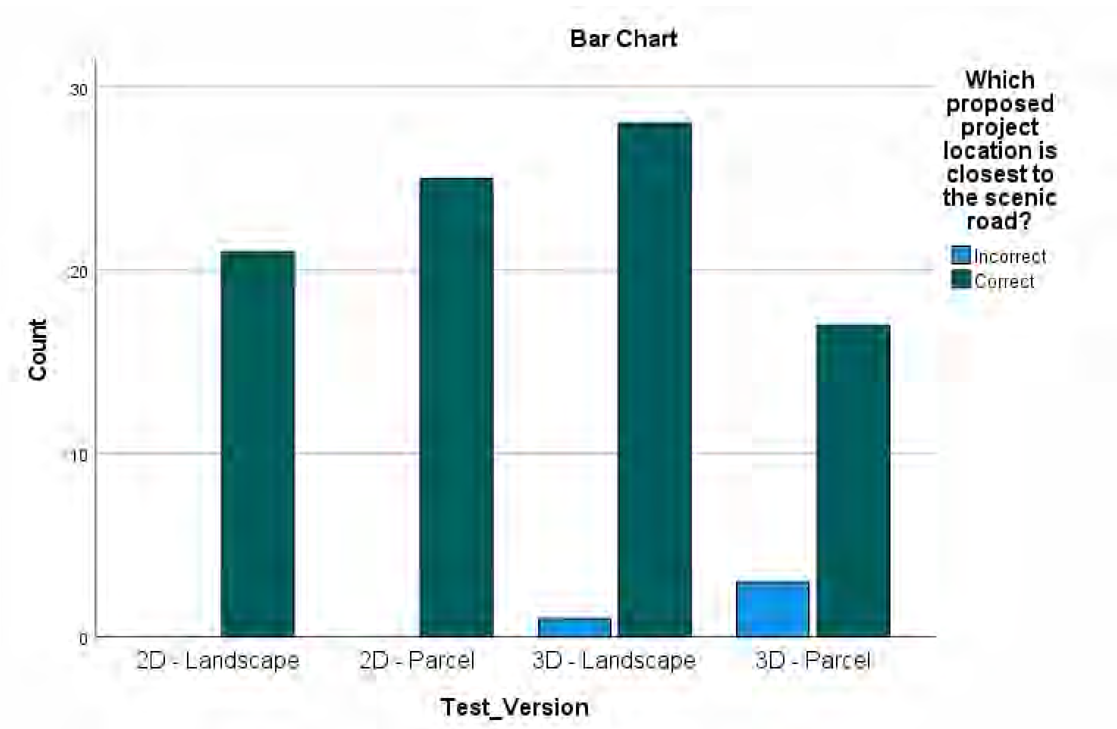


Test_Version * Which proposed project location is closest to the scenic road? Crosstabulation

Count

		Which proposed project location is closest to the scenic road?		
		Incorrect	Correct	Total
Test_Version	2D - Landscape	0_a	21_a	21
	2D - Parcel	0_a	25_a	25
	3D - Landscape	1_a	28_a	29
	3D - Parcel	3_a	17_b	20
Total		4	91	95

Each subscript letter denotes a subset of Which proposed project location is closest to the scenic road? categories whose column proportions do not differ significantly from each other at the .05 level.

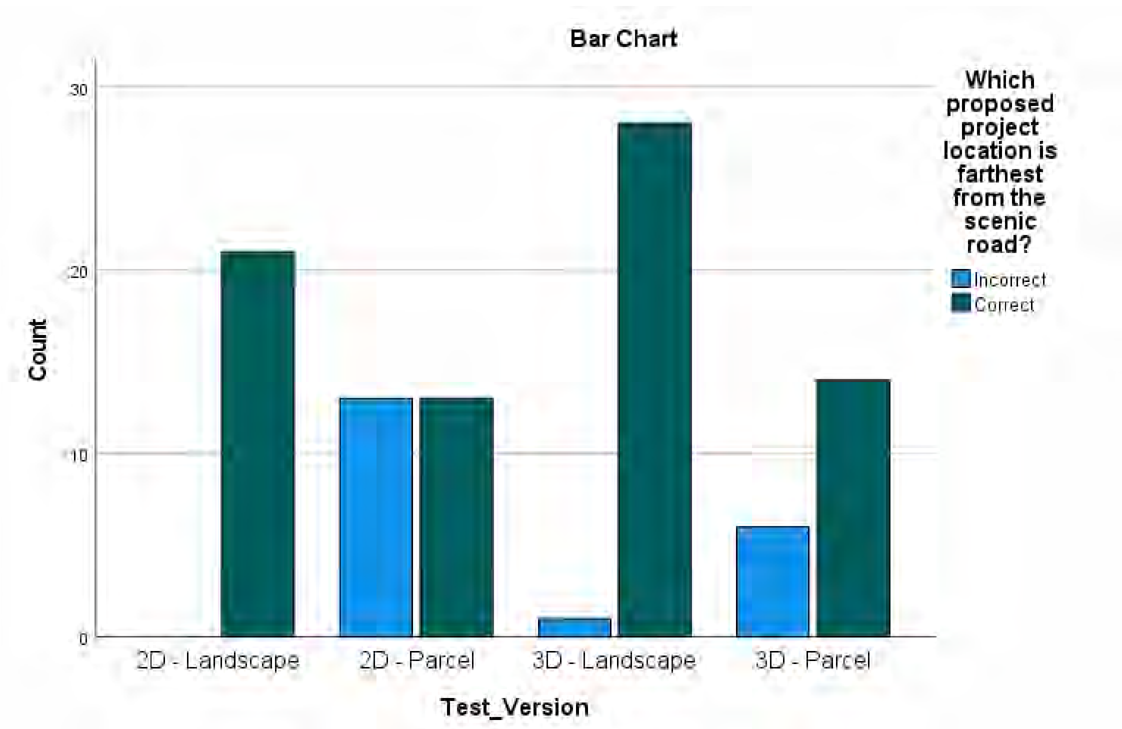


Test_Version * Which proposed project location is farthest from the scenic road? Crosstabulation

Count

		Which proposed project location is farthest from the scenic road?		
		Incorrect	Correct	Total
Test_Version	2D - Landscape	0_a	21_b	21
	2D - Parcel	13_a	13_b	26
	3D - Landscape	1_a	28_b	29
	3D - Parcel	6_a	14_a	20
Total		20	76	96

Each subscript letter denotes a subset of Which proposed project location is farthest from the scenic road? categories whose column proportions do not differ significantly from each other at the .05 level.

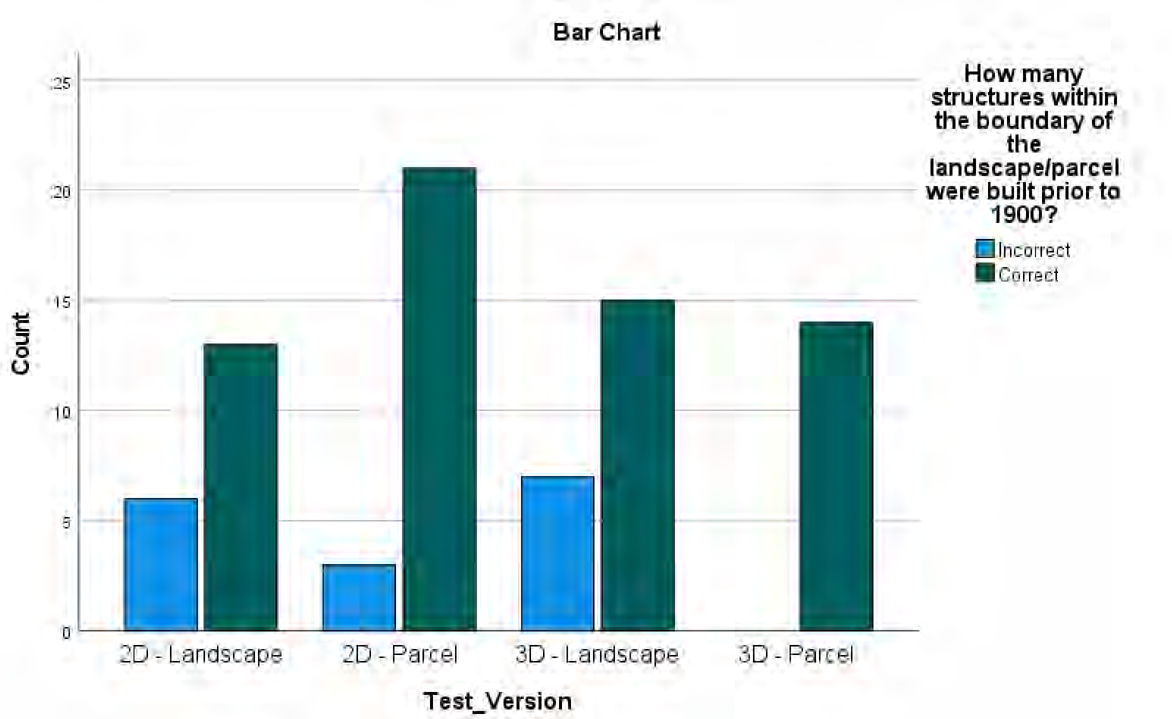


Test_Version * How many structures within the boundary of the landscape/parcel were built prior to 1900? Crosstabulation

Count

		How many structures within the boundary of the landscape/parcel were built prior to 1900?		
		Incorrect	Correct	Total
Test_Version	2D - Landscape	6_a	13_a	19
	2D - Parcel	3_a	21_a	24
	3D - Landscape	7_a	15_a	22
	3D - Parcel	0_a	14_b	14
Total		16	63	79

Each subscript letter denotes a subset of How many structures within the boundary of the landscape/parcel were built prior to 1900? categories whose column proportions do not differ significantly from each other at the .05 level.



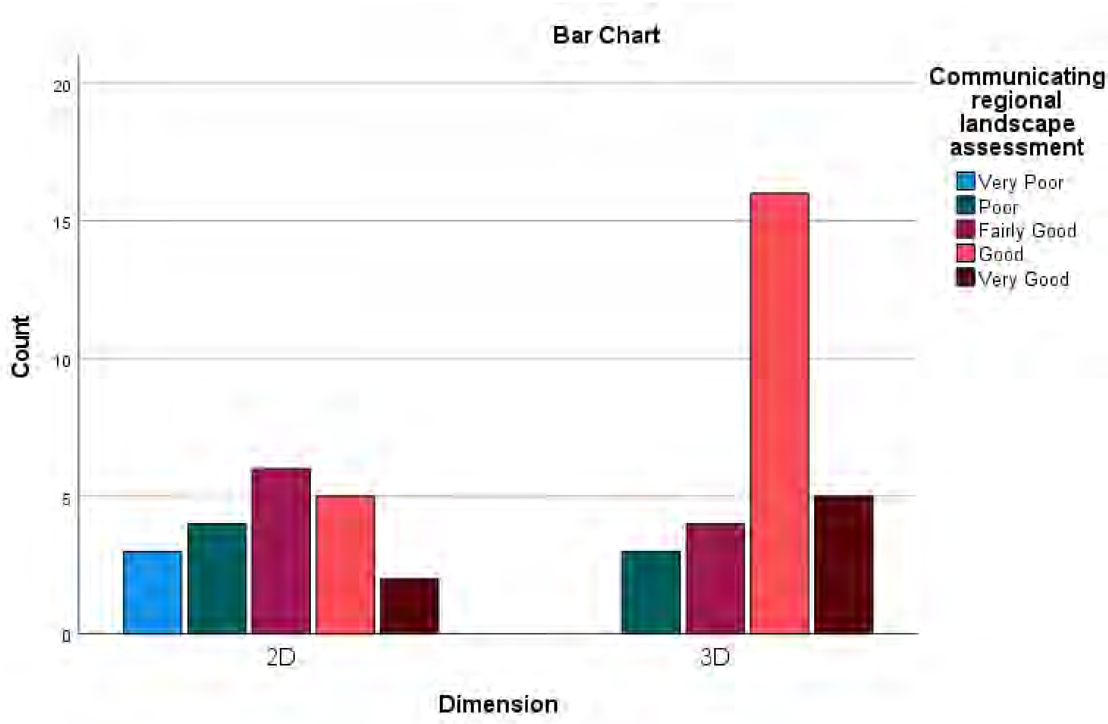
Appendix G: Map Usefulness – Question Responses

This appendix includes summaries of the responses to individual map usefulness questions.

Dimension * Communicating regional landscape assessment Crosstabulation

Count

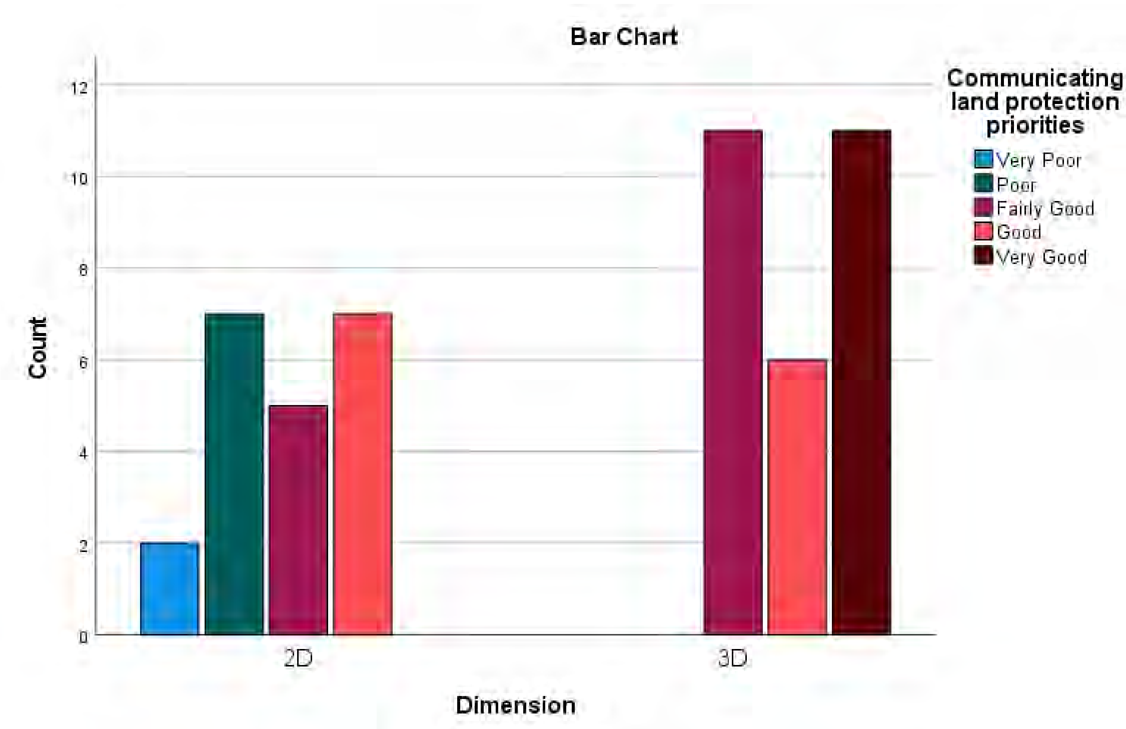
		Communicating regional landscape assessment					
		Very Poor	Poor	Fairly Good	Good	Very Good	Total
Dimension	2D	3	4	6	5	2	20
	3D	0	3	4	16	5	28
Total		3	7	10	21	7	48



Dimension * Communicating land protection priorities Crosstabulation

Count

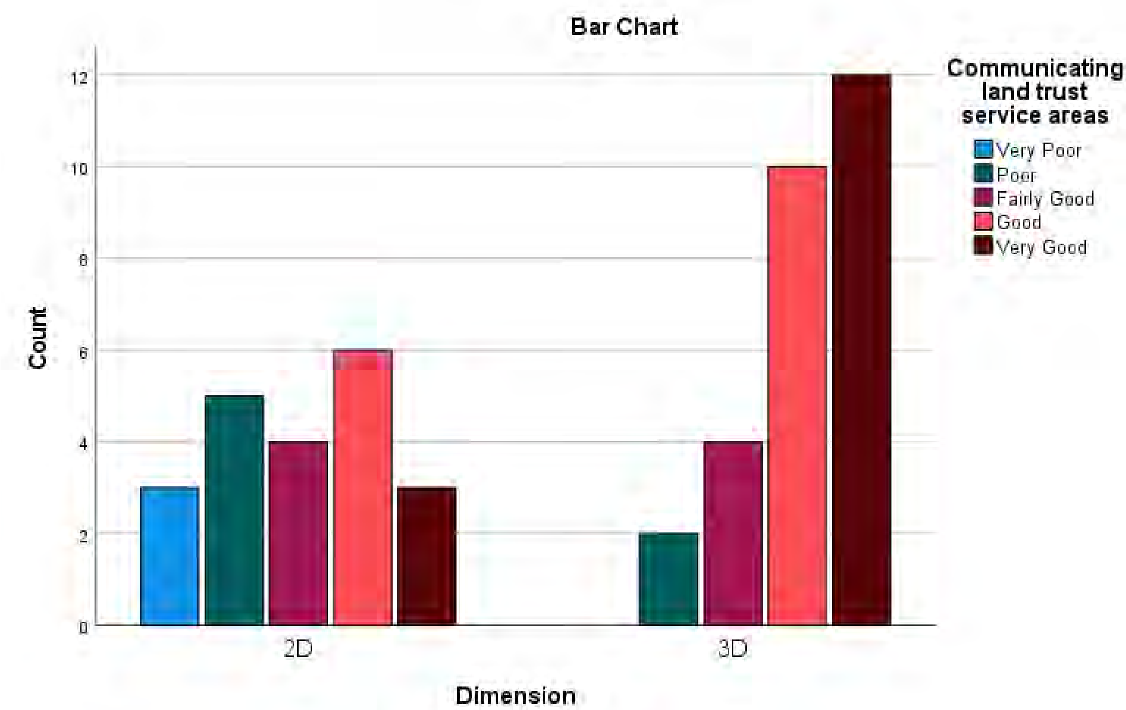
		Communicating land protection priorities					
		Very Poor	Poor	Fairly Good	Good	Very Good	Total
Dimension	2D	2	7	5	7	0	21
	3D	0	0	11	6	11	28
Total		2	7	16	13	11	49



Dimension * Communicating land trust service areas Crosstabulation

Count

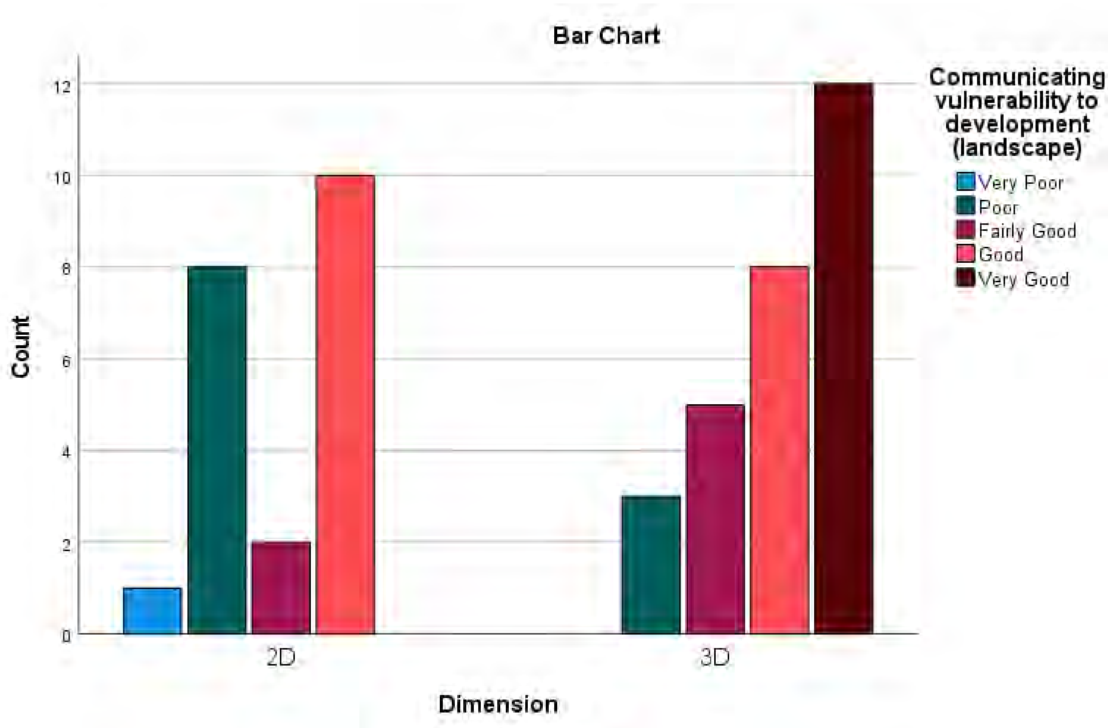
		Communicating land trust service areas					
		Very Poor	Poor	Fairly Good	Good	Very Good	Total
Dimension	2D	3	5	4	6	3	21
	3D	0	2	4	10	12	28
Total		3	7	8	16	15	49



Dimension * Communicating vulnerability to development (landscape) Crosstabulation

Count

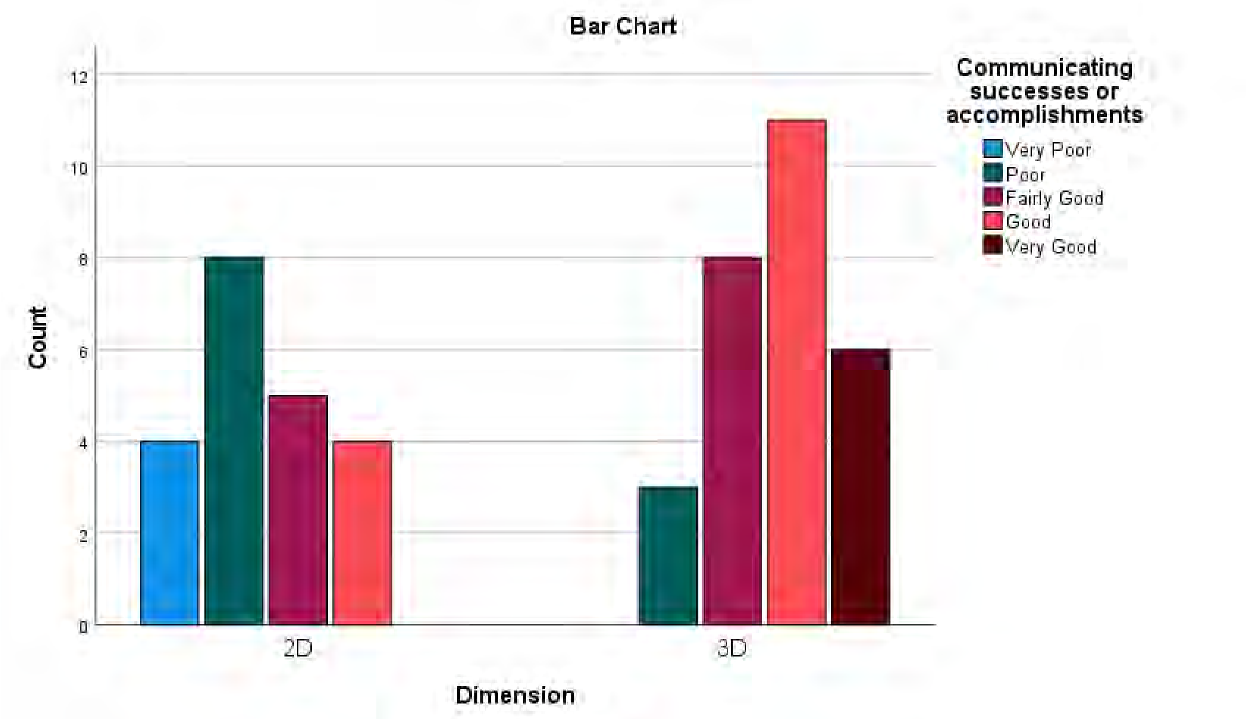
		Communicating vulnerability to development (landscape)					
		Very Poor	Poor	Fairly Good	Good	Very Good	Total
Dimension	2D	1	8	2	10	0	21
	3D	0	3	5	8	12	28
Total		1	11	7	18	12	49



Dimension * Communicating successes or accomplishments Crosstabulation

Count

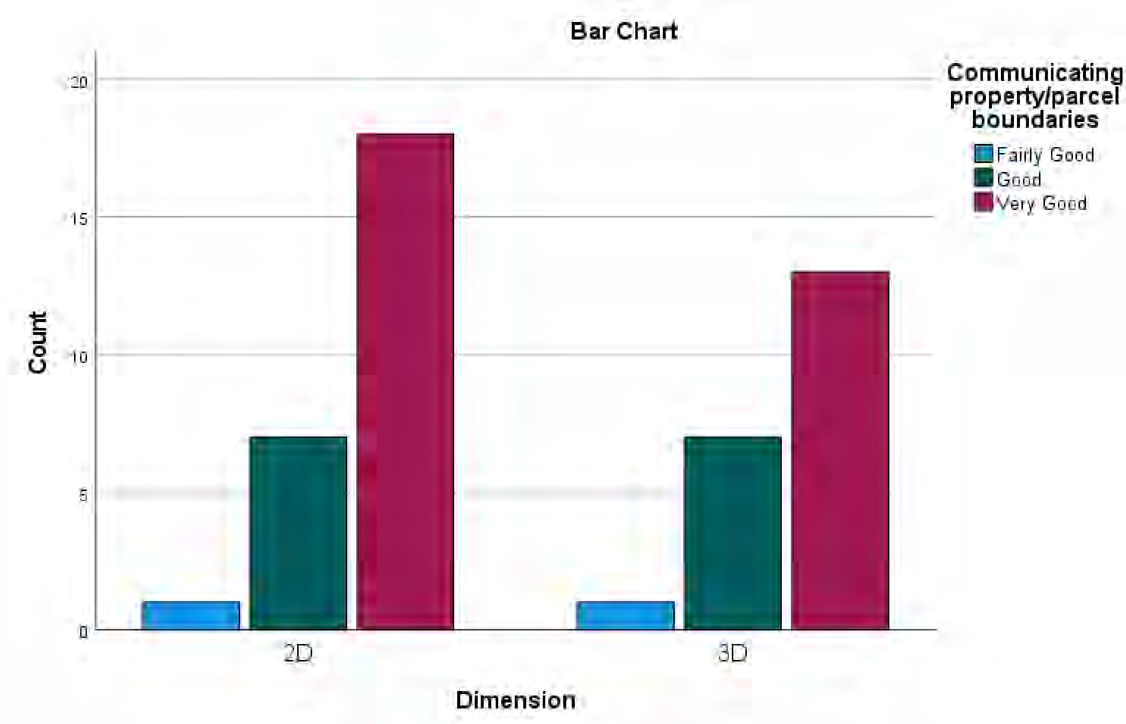
		Communicating successes or accomplishments					
		Very Poor	Poor	Fairly Good	Good	Very Good	Total
Dimension	2D	4	8	5	4	0	21
	3D	0	3	8	11	6	28
Total		4	11	13	15	6	49



Dimension * Communicating property/parcel boundaries Crosstabulation

Count

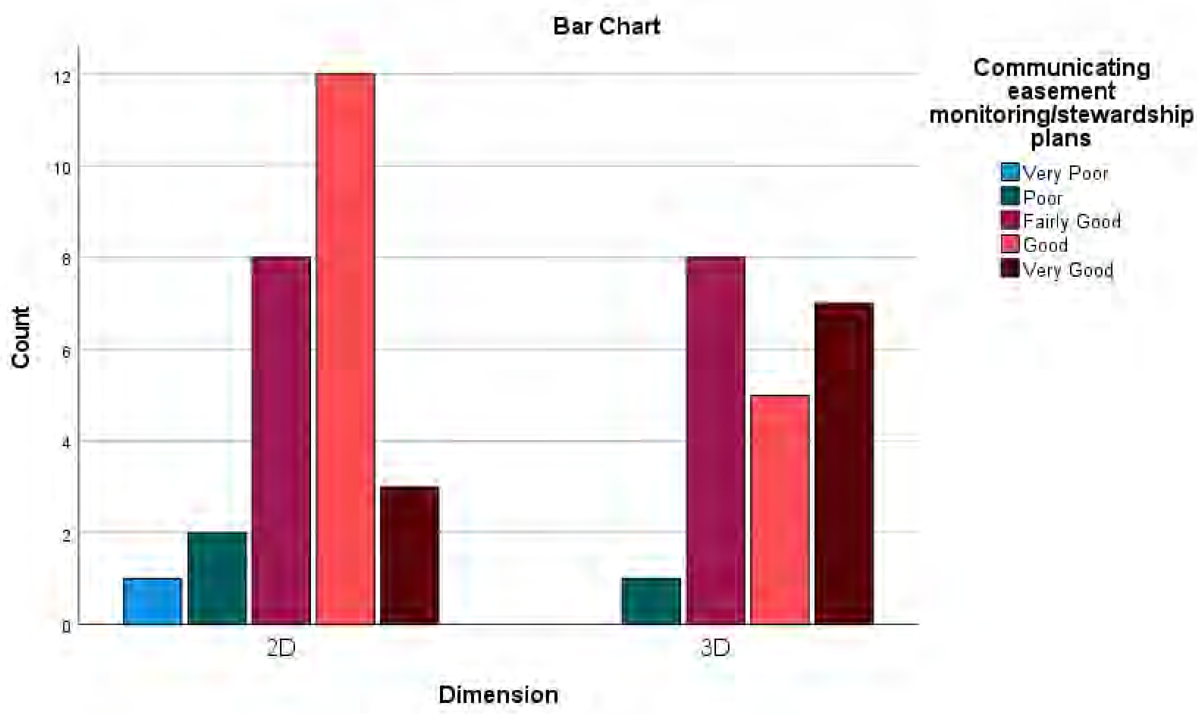
		Communicating property/parcel boundaries			
		Fairly Good	Good	Very Good	Total
Dimension	2D	1	7	18	26
	3D	1	7	13	21
Total		2	14	31	47



Dimension * Communicating easement monitoring/stewardship plans Crosstabulation

Count

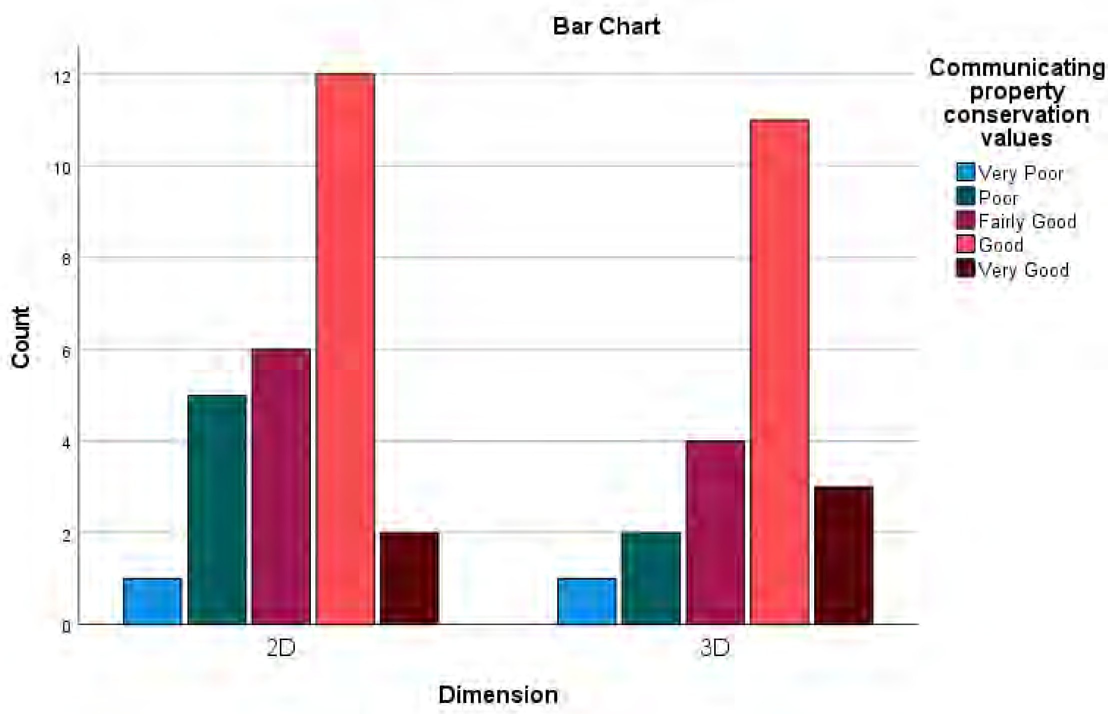
		Communicating easement monitoring/stewardship plans					
		Very Poor	Poor	Fairly Good	Good	Very Good	Total
Dimension	2D	1	2	8	12	3	26
	3D	0	1	8	5	7	21
Total		1	3	16	17	10	47



Dimension * Communicating property conservation values Crosstabulation

Count

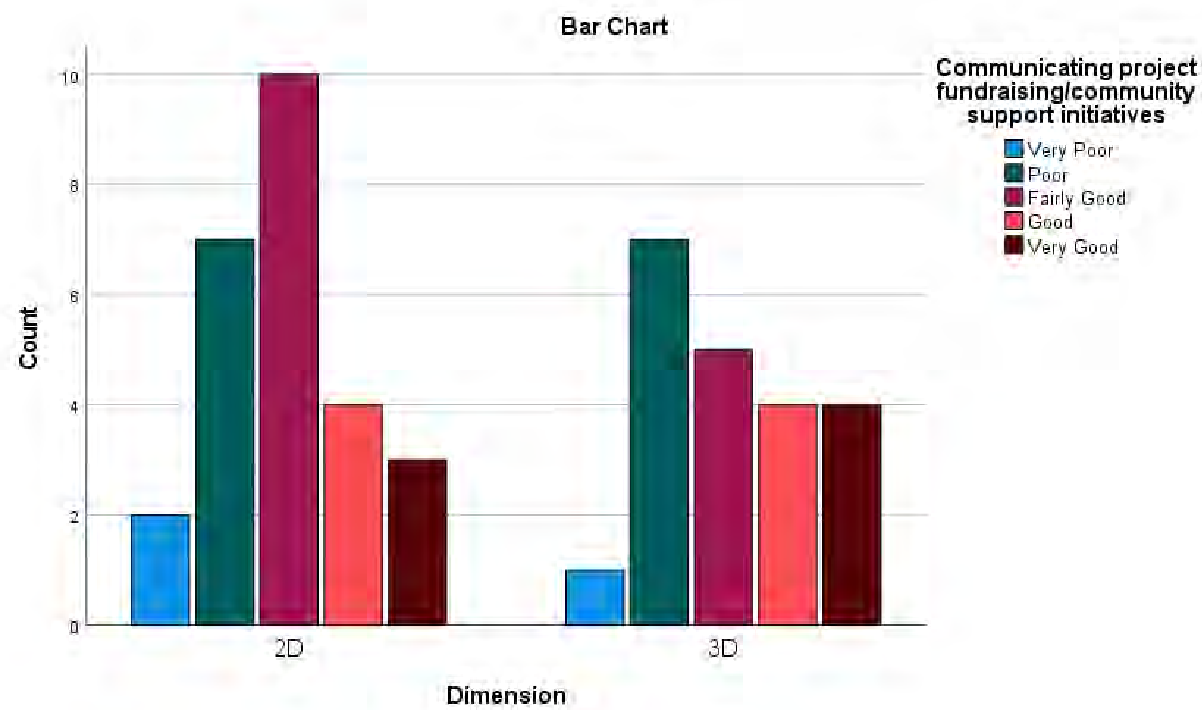
		Communicating property conservation values					
		Very Poor	Poor	Fairly Good	Good	Very Good	Total
Dimension	2D	1	5	6	12	2	26
	3D	1	2	4	11	3	21
Total		2	7	10	23	5	47



Dimension * Communicating project fundraising/community support initiatives Crosstabulation

Count

		Communicating project fundraising/community support initiatives					
		Very Poor	Poor	Fairly Good	Good	Very Good	Total
Dimension	2D	2	7	10	4	3	26
	3D	1	7	5	4	4	21
Total		3	14	15	8	7	47



Dimension * Communicating vulnerability to development (parcel) Crosstabulation

Count

		Communicating vulnerability to development (parcel)					
		Very Poor	Poor	Fairly Good	Good	Very Good	Total
Dimension	2D	1	7	7	7	4	26
	3D	1	3	8	5	4	21
Total		2	10	15	12	8	47