Where Geospatial Software Development and Video Game Development Intersect:

Using Content Analysis to Better Understand Disciplinary Commonalities and Facilitate Technical Exchange

by

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To my dad, who bought me my first map and my first video game

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Abbreviations

DAU	Daily active users
GIS	Geographic information system
GISci	Geographic information science
GIST	Geographic information system technology
HCI	Human-Computer Interaction
MAU	Monthly active users
MMOG	Massively multiplayer online game
SME	Subject matter expert
SSI	Spatial Sciences Institute
USC	University of Southern California

Abstract

This work endeavors to elucidate the parallels in technical methodology between the geospatial and video game development communities in order to understand how these methods can be harnessed by technologists within the domain of GIST. By understanding the core technical principles, software, and use cases that serve to mitigate and manage the core challenges shared between GISci technologists and game developers, this study aims to progress the standard technical workflow within GIST in learning from this sphere. An in-depth literature review surrounding the relationship between the two fields and the strategies used to conquer issues ranging from spatial data acquisition to graphics processing challenges followed by a qualitative investigation comprised of 16 interviews with subject matter experts (SME)s in both the GIST and gaming arenas was conducted in arriving at this study's findings. Core elements of human computer interaction (HCI) techniques from navigation/wayfinding strategies to scaled representational methodologies such as and multidimensional depictions of the environment were central to the investigation of shared methodological approaches examined between these two fields to appreciate the manner in which game development methods can be applied within GIST.

The major types of analyses used within this study of these two domains were based on an in-depth literature review on this intersection together with subject matter expert interviews from those in the GISci and gaming arenas. By uncovering the manner in which the gaming community can pass on technical knowledge onto GIST, this study hopes to illuminate a greater understanding of the way in which both domains can learn and collaborate with one another to create a shared community body of knowledge and grow from this methodological exchange.

Chapter 1 Introduction

This project aimed to investigate the methodological and technical points of benefit that geographic information system technology (GIST) can garner from video game development. In rooting out the technical components around these two key concepts in video game development, the GIST technical body of knowledge has much to gain. Throughout this thesis, the use of the word "technical" refers to the workflow and software-oriented processes in use by technologists in both the game development and geospatial arenas.

1.1 Motivation

Technology, like art, must borrow from the great masters in adjacent genres and across time to transform and meet the needs of the consumer. Such a relationship accurately characterizes the shared commonalities and intricately overlapping history of the gaming and digital mapping industries. While the video game industry has often borrowed from key technical concepts, the GIST community has only in recent years come to recognize the core technical concepts shared between the geospatial and gaming industries. There is much the GIST community can learn from the gaming community's technical methods. The gaming industry has, in and of itself, borrowed from GIST as it evolved and gaming platforms became more complex. GIST, on the other hand, has not applied the same degree of exchange and attribution of technical concepts in bringing in methodology from the gaming development world. Additionally, given the perspective of the author and driver of the work coming from a geospatial orientation, this orientation felt like a more appropriate fit compared to the opposite perspective. Having delved into the literature from GIST and video game developers, technologists, and academics, the key technical elements which GIST can learn from in understanding the cartographic interfaces in the gaming world centrally surround terrain generation processes and Human Computer Interaction (HCI) methods. This project attempted to draw on a bevy of works from the geospatial and gaming communities from both largely academic sources as well as interviews with Subject Matter Experts (SME)s across the geospatial and game development domain to better appreciate the technical methodologies applied by those within the gaming world can be adapted in service of the GIST community. Critical technical challenges between these two domains were broken down to best determine how game development methods and mitigation techniques within their technical methodology can be used in service of those within the world of geographic information science (GISci). Much can be gained for the GIST community from unpacking and understanding with greater depth positionality and spatial data acquisition and use in the game engine.

1.2. Study Area

This study focused on the technical concepts, methodological approaches, and technical mitigation strategies that can be applied from the game development world to the GIST realm. It is first imperative that the work define the arenas of GIST and the commercial video gaming industry. A strict definition of GIST in this context is spelled out herein as it relates to other forms of geospatial computation. ‘Gaming’, in this study, referred to the *commercial* video gaming industry as distinct from gaming as applied to military gamified environments for training. To arrive at these definitions, relevant academic literature in the gaming and GIST disciplines was used to create a description. The definition of gaming in terms of the ‘videogame’ was similarly derived from academic gaming literature (Bergonse 2017; Arjoranta 2019). In diving into this literature, the tailored understanding of gaming in terms of ‘video gaming’ fits the definition laid out in a recent paper from the *Journal of Computer Graphics,* which sets out the description of gaming in this thesis work as a played on an audiovisual apparatus which facilitates an entertainment-based interaction between the player, other players, a machine, and an electronic visual display within a fictional context that sustains an emotional attachment between the player and the game. This understanding of gaming draws on industry and academic contexts to arrive at a fitting term for the technical concepts that GIST can draw upon with reference to gaming and the gaming industry. GIST in this context can be defined as relating to GIS and digital mapping from Folger (2011), which includes a broader and more expansive definition of this term which includes developers in addition to GIS-technologists who solely make use of GIS software platforms. In this regard, GIST speaks to a broader geospatial and GIS-orientation of the term drawn from Chrisman (1999) and Gong et al. (2007).

The thesis work touches on mapping in the context of the commercial video gaming industry, and how positionality and spatial data acquisition as key technical concepts can be understood with great depth in the context of the game engine and how these might be applied to the world of GIST. In this context positionality can be seen as characterized in academic literature in GIST such as Ricket et al. and positionality as laid out in the context of gaming academia found in Taylor (2002). In drawing on an appreciation of this core technical concept, the literature points to a larger discussion around four specific elements shared by both disciplines 1) the core principles in human computer interaction (HCI), 2) scale and representation, 3) working with 2D and 3D models of space, and4) improving the approach to wayfinding strategies. Analyses were centered on the way in which GISci can divine a better understanding of these technical concepts with regard to these four main central points of analysis in analyzing how positionality plays a role and what geospatial technologists can learn from the specific methods of gaming developers. Multiple academic sources within the gaming and geospatial communities were reviewed to dissect the nature of the technical components and elements used within video game development that might be utilized by the geoscience community. Positionality plays a key role from the perspective of both the map-creator and the user. In GIST, the concepts surrounding positionality, from human computer interaction (HCI) to issues of scale and representation are key challenges that the GIST technical workforce must grapple with. In examining the phrase spatial data acquisition in the context of this thesis, a definition of this phenomenon and the issues surrounding it in both industries was taken from GIST academic literature such as Athanasis (2009) and this concept in the context of gaming such as the understanding of spatial data capture detailed in Dariusz (2016). As gaming has become more complex in format and structure, working with new data types has become a subject of academic conversation on the technical benefits of specific types of spatial types for effect or construction of game terrain. The body of knowledge with GIST at present can benefit greatly for more adeptly appreciating and applying the methods employed in video game development around this subject. Additionally, the sources below discuss some of the issues that occur in mitigating and managing the challenges of converging spatial data types together.

Moreover, this paper covers gaming platforms across consoles and formats to describe the manner in which digital cartography touches user interface and creation in video gaming. To that end the key technical elements of positionality and spatial data acquisition in terms of their methodologies and overlap in both domains are laid out with great detail. In service of the major feature of the analysis applied in the methodology used in service of this study, the qualitative analysis conducted using NVivo software, applied a strict list of definitions for each of the 'codes' applied within the context of this study. Given that the codification of the interviews comprised a substantive portion of the analysis applied in service of the methodology applied in service of this study, the rationale behind decisions made related to where/when each code in

NVivo was applied is described in greater detail in Chapter 3 which centers on the methods used in this study.

1.3. User Audience

This paper aims to investigate the manner in which GIST can grow through the application of technical processes around positionality and spatial data use in the case of video game development. The larger dimensions from which GIST can gain greater technical knowledge from the video game community break down along the historical use of these challenges in the video game domain and how they relate to GIST, spatial analysis methods to draw out these concepts, key software and data use parallels, and will be supplemented through a technical workflow as well as an investigation guided by a conversation with technical creators and contributors in either area. In tailoring analysis and investigation to these larger corresponding likenesses between the two fields, this thesis was intended to be relevant to geospatial academics and will be targeted to this audience. However, understanding where the GIST community diverges/learns from within video game development can be of interest to gaming academics, historians, and enthusiasts. This thesis also sought to capture the historical elements of the two professional disciplines which may be relevant to how GIST can learn from the gaming industry's technical approach to spatial data and positionality. Discussions of potential informal avenues of research through conversations with technical leaders in either field revealed a sudden wellspring of interest across the geospatial engineering and GIS analyst communities to appreciate how these concepts are understood in gaming and how they might learn from the commonalities and approaches to these core technical concepts. This research was therefore conducted in the hope that technical innovators in the geospatial field specifically will have a better understanding of where GIST can grow in connection to the gaming industry's approach to these concepts.

1.4. Environmental Importance

From the history of Pokemon Go to Google Earth, these two sectors share an intricate relationship the likes of which many GIS professionals may have little appreciation of (Engel 2019). As GIS analysts, software engineers, and even C-suite executives trade information and methodological approaches between these two professions, exposing how the GIST workforce and academic community can garner knowledge from the gaming world can help pave the way for GIS professionals in the future. At present, while some academic and scholarly work has discussed the relevance of cartography and planometric mapping structures to mixed reality (Augmented Reality (AR) and Virtual Reality (VR) gaming platforms, little work has been done exposing technical methodologies from game development that might be applied in the geospatial space. It is my hope that this work carries with it environmental importance in either technical domain of GIS over time.

Chapter 2 Background

2.1 Background

While approximately 800,000 users engage and delight in Niantic's Pokemon Go each day, rushing to 'Pokestops' to collect rare Pokémon and navigating the game's real-world map interface, few may be aware of the app's intricately interwoven relationship with the birth of Google Maps. To that end, Google Maps and Google Earth, can in fact be credited as the initial springwell from which Pokémon Go and the genesis of Niantic as a whole as it exists today. In 2001, John Hanke together with other geospatial technologists founded a startup called Keyhole. Keyhole, acquired by Google in 2004, laid the foundation for Google Maps as it exists today, which can be seen by many as the world's most popular and widely used GIS in human history.

Six years following Google's acquisition of Keyhole, Niantic Labs was born. Niantic's first release, Ingress, allowed players the ability to (in a highly similar format to that of Pokémon Go), meet at different geographic locations in order to fight in game space. Ingress garnered millions of users but was only the predecessor game to Niantic's now widely popular title, Pokémon Go. The relationship between the birth of Google Geo and Niantic's widely popular title Pokémon Go, marks just one of many threads in the interwoven relationship between the geospatial and gaming worlds.

To understand this interrelationship, one must first appreciate the emergence of cartographic interfaces within gaming. These maps appeared, given their paper format, in 2D view. Dungeons and Dragons (D&D), represents a game created within a board-game format which served as a source of inspiration for game developers from the incipience of personal computers (Toups et al. 2019). Programmers strived to mimic the spatial cognition and composition of the game map laid out on the board within digital-grid based map systems

(Williams 2017). In the late 1970s and early 1980s, Nintendo game maps served to mimic the first-person game-based directionality of D&D and other paper-derived board games through user-movement described in terms of direction. The numerical mechanics of paper-based game maps were particularly instructive for programmers at the dawn of early personal computers and the dawn of computing with the rise of titles which applied a maze-based structure such as Namco's Pac-Man (Figure 1).

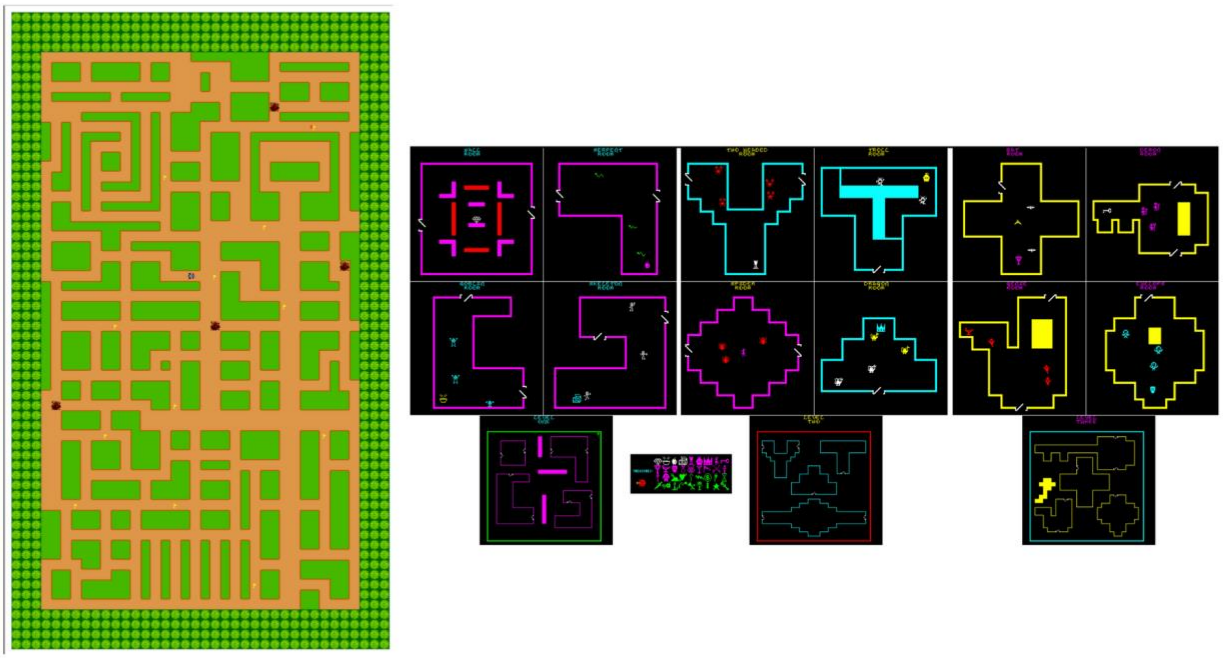

Figure 1. Early video game maps of (left) Namco's Rally-X circa 1980 and (right) Exidy's Venture circa 1981, which relied on a grid-based structure 2D-generated structure.

As game development progressed, the dimensionality of the video gaming adapted experientially with it. This prompted a rise in a multiplicity of game maps when viewing game space. Early adaptations of this methodology can be found in titles such as the 1980s release of A.I. Game's Rogue the interface for which allowed for partial view of the geographic composition of the map within the game environment (Toups et al. 2019).

The ability to see the game directionally from different viewports allowed for a newfound game experience which was furthered by the inclusion of 3D game space which allowed for a game interface that included a Z-axis. Despite the immersiveness of the game experience and the receptiveness among players to this diegetic submerge into the 3D gameworld, 2D maps remained within the interface as a beacon and source of reference for players while traversing a game (Aranda et al. 2009). A larger trend toward game-board expansion together with the use of 3-dimensional portrayals of game space cartographically, prompted the need for high quality graphics processing to maintain the game interfaces's graphical integrity while simultaneously prompting the need for high-level computing power in order to manage multiple instances of game players on the same game across the globe (Dobkin 1992; Toups et al. 2019).

2.2. Parallel Obstacles Across Domains

The addition of 3D data brought with it a myriad set of challenges for those in the geospatial arena and game development community. From a technical and methodological history perspective, the domain of GIST is quite familiar with the difficulties associated with processing and working with separate types of data file formats (Breunig et al. 2020). Particularly with the rise of 3D geospatial data in recent years, 3D data types have been rapidly included into standardized GIS workflows much in the same manner as it has with the advancement and development of game development (Toups et al. 2019). Given that GIS at its birth developed as a software system from a 2D paper-based system, struggles surrounding the input of spatial data into a cartesian system carried with it significant methodological impediments particularly as the number of spatial data file types continuously increased (Christman 2006).

To this day, those within GIST are often met with issues in working with different spatial data types. The sheer number of spatial data file types, to start, can be daunting with the Library of Congress citing over 50 different types of recognized geospatial data types from the ever-popular Esri Shapefile format to the Geodatabase format family of data types (Devillers 2006). Moreover, further specialization can be found stemming from the companies that release these spatial data file types which have become adopted by the wider geospatial technology community. ERDAS Imagine, for example, releases its own widely popular ERDAS IMG format accepted for use by many within the geospatial remote sensing community and Esri currently offers 11 accepted file types by the Open Geospatial Consortium (OGC) (Nogueras-Iso et al. 2005). The OGC, the governing body concerning geospatial data standards releases its own set of accepted file formats (in addition to overseeing the larger community of geospatial technologists and geospatial technology standards) from the GeoPDF to the GeoPackage Encoding Standard family of data types (Zarazaga-Soria 2005; Breunig 2020). Beyond these organizational or company-generated file formats, larger families of file formats break these spatial data types into further groups between raster, vector, and point level file formats (Neteler et al. 2004). The challenges that exist in handling and reconciling the ever-growing quantity and vastness of geospatial data formats while preserving data integrity cannot be overstated particularly in light of recent technological developments and advancements toward the inclusion of 3D geospatial data formats. From a future forward looking perspective, an even wider degree of file formats can and likely will be found and put into use by geospatial technologists in common practice what with recent developments towards the use of 3D geospatial data formats as well as LiDAR and photogrammetry data formats in use by geospatial professionals.

2.3. Learning, Adapting, and Growing by Example

The desire to mitigate and manage these and other such methodological issues require problem solving that is as complex as it is multifaceted. Troubleshooting methodologies in combating these problems stand to benefit enormously from a geospatial perspective in looking to the gaming world for potential means of managing these issues. A corollary experience in examining the technical development and history behind the adjustment made to generate a graphical output from a paper-based format combined with the added challenge of adapting to the inclusion 3D-datasets similarly has offered further complicated the workflow for game developers in applying the inclusion of these file types into the softwares themselves. As new types of 3D modeling softwares emerged on the market as the popular forms of 3D geometry and mesh manipulation for those within the game development and design domain and with this software came unique file types inherent to each (Toups et al. 2019; Evangelidis et al. 2018). With each new file type introduced into standardized workflows, came a myriad of issues from data integration (in addition to coordinate geometry) unique to these software systems (Burenhult 2008).

2.4. Definitional Background for Terms in Use

A strict definition of GIST in this context will be spelled out in the paper as it relates in this context to other forms of geospatial computation. 'Gaming', in the context of this paper will speak to the *commercial* video gaming industry as distinct from gaming as applied to military gamified environments for training. To arrive at these definitions, academic literature in the gaming and GIST disciplines was drawn upon to carve out a sufficient description. The definition of gaming in terms of the 'videogame' in academic gaming literature is the one that will be applied here (Bergonse 2017; Arjoranta 2019). In diving into this literature, the tailored understanding of gaming in terms of 'video gaming' fits the definition laid out in a recent paper from the *Journal of Computer Graphics*, which sets out the description of gaming in this thesis work as a played on an audiovisual apparatus which facilitates an entertainment-based interaction between the player, other players, a machine, and an electronic visual display within a fictional context that sustains an emotional attachment between the player and the game. This understanding of gaming draws on industry and academic contexts to arrive at a fitting term to appreciate the technical concepts that GIST can draw upon with reference to gaming and the gaming industry. GIST in this context can be defined as relating to GIS and digital mapping from Folger (2011). In this regard, GIST speaks to a broader geospatial and GIS-orientation of the term drawn from Chrisman (1999) and Gong et al. (2007).

The thesis work may touch on mapping in the context of the commercial video gaming industry, and how positionality and spatial data acquisition as key technical concepts can be understood with great depth in the context of the game engine and how these might be applied to the world of GIST. In this context positionality can be seen as characterized in academic literature in GIST such as Ricket et al. and positionality as laid out in the context of gaming academia found in Taylor (2002). In drawing on an appreciation of this core technical concept, the literature points to a larger discussion around four specific elements shared by both disciplines 1) the core principles in human computer interaction (HCI), 2) scale and representation, 3) working with 2D and 3D models of space, and4) improving the approach to wayfinding strategies. As the examination of this concept expands within these two disciplines expands and broadens in depth, the analysis centers on the way in which GISci can divine a better understanding of these technical concepts with regard to these four main central points of analysis in analyzing how positionality plays a role and what geospatial technologists can learn from the specific methods of gaming developers. Many academic sources within the gaming and geospatial communities were used to dissect the nature of the technical components and elements used within video game development that might be utilized by the geoscience community. As the researcher reflected on the ways in which these technical methodologies within the gaming community can be applied to the mapping world, she was also sure to accrue more GIST academic literature in this section. Positionality plays a key role from the perspective of both the map-creator and the user. In GIST, the concepts surrounding positionality, from human computer interaction (HCI) to issues of scale and representation are key challenges that the GIST technical workforce must grapple with.

In examining the phrase spatial data in the context of this thesis, a definition of this phenomenon and the issues surrounding it in both industries will be taken from GIST academic literature such as Athanasis (2009) and this concept in the context of gaming such as the understanding of spatial data capture detailed in Dariusz (2016). As gaming has become more complex in format and structure, working with new data types has become a subject of academic conversation on the technical benefits of specific types of spatial types for effect or construction of game terrain. The body of knowledge with GIST at present can benefit greatly for more adeptly appreciating and applying the methods employed in video game development around this subject. Additionally, the sources below discuss some of the issues that occur in mitigating and managing the challenges of converging spatial data types together. An extensive literature review was conducted on this subject technical aspects surrounding the mapped surfaces of virtual environments in gaming.

Chapter 3 Methods

This chapter describes the methodological approach to an analysis of the technical lessons that GIST can learn from the video game development community. The methodology for this thesis goes beyond a standard GIS technical work to a qualitative investigation of the literature surrounding the technical methods that the geosciences community can teach game developers. The literature review process described in Section 3.2 provides an overview of the approach to the literature review of the connection between the technical methodology currently in use in both the geospatial and game development communitities. The majority of the analysis conducted for this body of work relied upon interviews with subject matter experts (SME)s in the 1) geospatial academia, 2) geospatial industry. 3) video game academia, 4) gaming industry experts. All qualitative research and its resulting analysis were conducted using NVivo software, the process and codification of key terms for which is described in depth in Section 3.2.

3.1 Methods Overview

The literature and interview-based methodology applied in the work aimed to uncover and better understand how the technical methods currently in use by GIS technologists that may be employed to the benefit and service of game development work is centrally focused by the use of technical methods central to spatial data acquisition and positionality. While issues surrounding these two technical concepts require unique solutions in the GIST arena, the way in which geospatial technologists approach these two concepts, while seemingly unique to the GISci community, has particular relevance to current challenges encountered in the game development sphere.

3.2 Literature Review Methodology

As described in the related literature section below, the research process surrounding the pre-existing literature on the relationship between the two domains was methodologically bifurcated into major sector and domain-based groups. This project aimed to unpack the technical approaches and challenges currently faced by video game developers and then align these issues to technical procedures that are harnessed by the GIST community. The crux of the literature review through this process was guided by the table of contents carved out above and separated succinctly into three major types of literature:

1. Academic research, discourse, journal articles and conference proceedings from the geospatial domain on the relationship of gaming to GIS and digital mapping principles were used.

2. Academic research, journal papers/related academic literature within the field of video game development with a specific focus on understanding the more programming and computer science-oriented understandings on the intersection that is the focus of this paper were also made use of in developing and expanding out the analysis for this study. Given that the work will mainly focus on the technical concepts of positionality and spatial data acquisition. Academic work was used as the main source of knowledge gathering used in the research process and literature review for the work.

3. Industry/trade magazines in both the geographic and the gaming-based domains---beyond Google search using services such as LinkedIn to discover further writing on the subject (further detail on the methodology behind this process detailed below).

To start, literature review and analysis was based within the context of geosciences and geospatial realm. Namely, the first step was exploring the sources provided in the International Journal of Geo-Information titled “Gaming and Geospatial Information” which speaks to this relationship from a variety of angles and perspectives (Bleasdale-Shepherd 2009). This volume of ISPRS, a respected academic journal within the geosciences community also served as a valuable source which provided further leads that have covered this subject. Literature within the world of geographic sciences and the academia surrounding it on this subject has also been produced by academics at Middlesex University's Geography Department where a fair degree of literature has been devoted to exploring the linkages between GIS and video game creation (Shepherd 2009). One of the pivotal series on cartographic work in the context of video game development has also come from Canadian Geographic, a scholarly journal from Canada which has produced a variety of papers on this subject (Kylie 2019).

The literature review process drew upon both GIS/geospatial related content as well as video gaming based interpretations and discussions surrounding the existing methods in GIST that mirror those found within the gaming arena. Academic journals in the context of the gaming world were used to help guide the manner in which the gaming industry and academia surrounding it reflects on mapping/cartographic practices in their work. For example, a variety of volumes from the Digital Games Research Association (ToDIGRA) represents just one of many academic journals in the gaming industry. Moreover, it was important to draw on sources derived from the perspective of the developer and those within the field of computer science. Journals in the domain of computer science and video game development that cover this subject include IEEE Transactions on Computational Intelligence and AI in Games, Simulation & Gaming: An International Journal of Theory, Practice and Research, and Elucedamos, a central video gaming journal on video game science and culture.

A variety of trade magazines which explore this subject matter were also used. Within the geospatial arena articles have been written in Trajectory Magazine (Kleinsmith 2018), GIS Lounge (Borneman 2018), and Geo-Awesomeness (Buczkowski 2019) covering this subject. From the video gaming trade magazine and blog perspective, entire journal editions and blogs cover various aspects of this subject, including but not limited to EuroGamer (Hetfeld 2018), The Map Room (Crowe 2020), and Gamesradar (Lipscombe [2020] has published on the topic of the overlap between the geospatial and gaming-based arenas). A combined investigation of both scholarly and industry-related pieces on the relationship between digital mapping and entertainment-based video games hopefully led to a better understanding of the shared parallels that exist between the two fields.

3.2.1. Literature Review Process Breakdown

In the expanded literature review search, not only were some of the more classic resources for academic work such as Google Scholar used to find GIST-based academic work, but so were conference proceedings from major geospatial or GIS conferences in the US and beyond to find resources for the thesis work. Exploring the citations and references of some of the relevant journal articles in the world of video game development and computer science led to a variety of related work that will be reviewed to better understand the intersection between the two fields.

Additionally, in finding GIS-related industry texts that might be relevant to the thesis, professional tools such as LinkedIn were used to find related articles about this subject that allowed further investigation of this subject. LinkedIn also provided a helpful window into collaborators or other writers on this subject whose articles might be relevant here. As the literature review process continued, game genres, geospatial technical workflows in studying this topic, and major GIS/geospatial academic papers or conference proceedings were identified. An in-depth study and analysis of literature reviews from academic peer-reviewed journals in both the geospatial and gaming arenas as well as trade magazines from the industries around both domains. This literature review was used to help bolster, supplement, and guide the extracted assortment of the findings provided by the in-depth technical discussions from SME interview via the coded network analysis, word frequency, and organizational evaluation and research.

3.3. Subject Matter Expert (SME) Interview Methodology

To start, the decision-making process and methodology behind the chosen list of interviewees began from experts in the geospatial world whose thoughts on the subject matter seemed potentially valuable. The interviews were broken down into 2 overarching groups (geospatial subject matter experts and video game subject matter experts). From there, the groupings were refined even further to geospatial/video gaming experts in academia and in industry. It is hoped that as the literature review and interview process deepens, more experts across both domains and within either of the sub-categories will be encountered. The final interview question asked interviewees if there were other experts at this intersection it might be good to talk with. A full template of the interview questions for the experts in this domain can be found in Table 1 below.

In identifying the experts already included on the interview list compiled so far, LinkedIn, Google Scholar, and some of the researcher's own contacts/findings through personal and professional exploration of this intersection were used. As the literature review process progressed, investigating the body of literature behind the connection between the technical methods employed in the gaming domain that may be bolstered via GIST technical concepts as

Cross-Domain SME Questions	**Geo-Related SME Questions**	**Gaming-Related SME Questions**
1.How do your career, research interests, area of study relate to (*insert where appropriate* GIST or video game development? 2.How have you come to understand the relationship (if	1.What technical methods do you feel those in the gaming arena might stand to benefit or learn from in the video game development arena? 2.Do you feel the GIST domain will be subject to an increasing trend toward gamification as the two	1.As a video game developer (or subject matter expert), to what extent do you notice the role of the map in game play? 2.What elements of gameplay are impacted by the dimensionality of the game-map?

Cross-Domain SME Questions	Geo-Related SME Questions	Gaming-Related SME Questions
any) between the GIST and gaming arenas? 3.How does spatial data acquisition play a role within (*insert where appropriate:* GIST or video game development)? 4.What difficulties do you experience in working with novel geospatial data types? 5.What role does positionality play within (*insert where appropriate:* GIST or video game) development? 6.In what way does dimensionality impact your work (*insert where appropriate:* GIST or video game development)? 7.What have been some of the most game-changing technical advancements in (*insert where appropriate:* GIST or video game development) and how has this impacted your own technical workflow and methods? 8.Given your expertise, are there other specialists or technologists you believe might be relevant to speak with through the research process that might be relevant to this project/body of work?	arenas continue to adopt increasingly complex methods of technical development? 3.Have you ever provided technical support to those in the gaming industry/video game development sphere as a GISci expert?	3.Are there video games that, in your view, typify some of the challenges that might benefit from the expertise of the geospatial technical community?

Table 1. Interview Questions for SMEs in GIST and Game Development Arenas

questions intended for more of a disposition toward GIST or game development although no differentiation to that extent was made in reference to the breakdown of academic vs. industry-based interviewees within the set of questions for the thesis study.

3.3.1. Interviewee Distribution Methodology

A variety of subject matter experts were interviewed using what was, at first, a tentative list of experts based upon previous research on this subject, which was then expanded to a larger list based upon those interviewees who responded to requests for an interview. It is very important to note here that while 40 interviewees were included in this list, the interviews were ultimately constrained by the number of SMEs who responded to requests for an interview. All told, 16 interviewees responded to requests for an interview for this study. The interviews were broken down into the following estimated distribution of interviewees across both domains to better appreciate the technical elements used in reference to spatial data acquisition and positionality in reference to the game engine and understand how GIST methods may be of use to this domain. A more broken-down list of interview candidates resulted in a total of 16 thesis interviews conducted for the qualitative analysis with an intentionally equitable distribution of geospatial and gaming related academics.

3.4. NVivo Qualitative Analysis Software Methodology for SME Interviews

A more extensive explanation of how this list of potential interviewees was assembled will be included in the research methodology. First, a tentative (and highly fluid) list of persons was assembled for interviews to collect information on the subject matter of the thesis. The list was ultimately determined based upon which SMEs responded to requests for an interview. The full table of these SMEs across fields and sectors (Table 2) consists of those candidates who got back to and sat down over video call or in person in response to requests for the interview. Following the granting of exemption from IRB oversight for the thesis interviews, conversations with these interviewees was able to commence. The list of interviewees (Table 2) was created in main reference to the literature review process conducted. After a comprehensive literature review process was conducted, experts mentioned in both the academic and industry-related literature were contacted in order to get their input.

	Geospatial SMEs	**Gaming SMEs**
Academia	GeoA 1, *USC Spatial Sciences Institute* GeoA 2, *University of Wisconsin* GeoA 3, *University of Delaware*	VGA 1, *University of Oklahoma* VGA 2, *University of Texas at Austin* VGA 3, *Northeastern University*
Industry	GeoI 1, *Cesium* GeoI 2, *Cesium* GeoI 3, *Mak Technologies* GeoI 4, *Google Geo* GeoI 5, *Google Geo*	VGI 1, *Amazon Lumberyard* VGI 2, *Disbelief Games* VGI 3, *Epic Games* VGI 4, *Nvidia* VGI 5, *Nvidia*

Table 2. Breakdown of academic and industry interviewees

All interviews were transcribed in-full following the conclusion of the interview. NVivo, a qualitative analysis software, was used to code the interviews and to look for common themes across the subject matter experts interviewed, as well as the interrelationships among these themes. NVivo is a widely used software for archiving and analyzing qualitative data. It is well-suited to the analysis of interview transcripts and is often the software of choice for academics seeking to generate publication-worthy textual analysis.

Following a deep-dive investigation into learning and understanding the methods of analysis available through the NVivo software, the qualitative analysis process was begun as it is commonly enacted in academic qualitative research. First, the files were uploaded to NVivo, categorizing them according to the professional role of each interviewee. These codes were drawn from an in-depth investigation of major themes across interviews in reflecting upon the interviews and drawing from the notes from each. An equitable distribution of common key themes along the geospatial, game development, academic, and industry interviewee keywords across the notes taken through these conversations ensured the coding process successfully identified corresponding themes from these interviews.

Each of the interview statements were gone over again, and across each transcript a corresponding list of relevant themes from the individual interview was generated and then these initial individualized interview-specific codes were matched to overarching motifs across the board. Themes were also developed based on the literature review, the goals for the project, and the IRB-approved questions asked each interviewee. Each theme was then entered as specific *codes* in NVivo. The codes listed are provided in Figure 2 below. This code list was pulled directly from the list of terms provided as reference within the NVivo software interface in reviewing and coding the interview transcripts for this study.

Name	Files	References
3D Data	7	65
AR or VR mention	10	37
Career Connection to Th...	14	61
Challenges with Different...	10	40
Coordinate Systems	5	11
Digital Twin	11	56
Dimensionality	10	48
Environmental Artist in G...	7	25
Favorite Game Map	0	0
Game Engine	11	42
Geo-Gaming Relationship	10	19
Geotypical or Geospecific	2	10
GPU	8	21
Graphics	12	82
Interactivity	8	50
Military	4	17
Navigation	9	32
Peer Recommendations	7	21
SIGRAPH	1	2
Simulation and Modeling	10	129
Spatial Data	12	60
Specific data type	11	63
Specifc Gaming Compan...	10	43
Specific Geospatial Com...	11	64
Specific Video Game Me...	11	57
Technical Advancements	12	39
WebGL	3	6

Figure 2. In-Software NVivo Major Code Headers

The next task was to establish reliability across the interview transcripts being coded to ensure the methodology applied in approaching the coding process was uniform for each transcribed conversation with the SMEs consulted for this investigative research. The same two sample interviews were read through, and the content was coded according to the written understanding of the codes. In creating this subtext definition for each of the potential codes across the set laid out for the interviewees conducted, a homogeneous standard for what was being described for the codes across the interviews across the different contexts or perspectives from which it was used.

Following the testing in terms of the reliability analysis conducted from after this initial coding (i.e., percent agreement and Kappa values), codes were then merged, divided, added and removed as needed. Creating these specific definitions for each code ensured a more cohesive approach to the coding across all selected key terms and themes through all of the interviews. Doing this enabled the researcher to operate from the same conceptual understanding of these key terms in coding through the writeups of these conversations with subject matter experts recorded for this project (Table 3).

Codes	Definition /Parameters Used to Apply Code to this Term
3D Data	Mentions to data that is 3D in relation to 3D geometric or 3D coordinate (x, y, z) data
AR or VR Mention	Any time that augmented reality (AR) or virtual reality (VR) is mentioned
Career Connection to Thesis Subject Matter	Description of how the individual being interviewed does research on or has work related to professionally the overall topic of the thesis or how their professional or research background relates to this thesis topic from the perspective of the gaming or geospatial arenas
Challenges with Spatial Data Types	Description of a specific issue in dealing with different kinds of spatial data types
Coordinate Systems	Use of the phrase “coordinate system” by the interviewee or a system more generally that uses one or more numbers, or coordinates, to uniquely determine the position of the points or other geometric elements within an interface

Codes	**Definition /Parameters Used to Apply Code to this Term**
Digital Twin	The interviewee makes use of the term “digital twin” or describes a virtual representation that serves as the real-time digital counterpart of a geographic location, physical object, or process (i.e., cases in which a city in which a video game is set which is modeled after a real world city (NY, Athens etc.)—can also apply to any time modeling of a video game world is modeled after a real-world environment generally (not necessarily a specific city could also be a place, mountain, general region etc.)
Dimensionality	Mention of the phrase “dimensionality” by the speaker or in response to questions about it to interviewees—this can be used in reference to the dimension of user experience to a 2D and then a 3D spatial extent or mathematical space within a geospatial or gaming context
Environmental Artist in Gaming	References to an environment artist within the game development sphere or to a professional artist within a video game development team who works as a 3D modeling for outdoor or indoor locations of a game's setting
Favorite Game Map	Used every time someone answers the question “what is your favorite video game map”
Game Engine · Unity · Unreal Engine	This is coded every time the phrase “game engine” is used with reference to a software framework primarily designed for the development of video games, and generally includes relevant libraries and support programs—this can also refer to the development software utilizing this framework, typically offering a suite of tools and features for developing games · *(Unity)* Describes the use of Unity as a game engine · *(Unreal Engine)* Refers to the use of Unreal Engine as a game engine platform
Geo-Gaming Relationship	Any time an interviewee more broadly answers the question “what do you see the relationship between geospatial and gaming being”

Codes	Definition /Parameters Used to Apply Code to this Term
Geotypical or Geospecific Data	Mentions of the phrase “geotypical or geospecific data” in reference to data that is either geotypical in that it bears a symbolic representation for a set of map features depicting a space as opposed to geotypical data which describes area that are to an exact and absolute extent bear a 1:1 relationship with the environment the game or geospatial modeler is attempting to simulate
GPU	References to the term “GPU” or general reference to the part of a computer needed for graphics processing
Graphics · Rendering · Shaders · Texturing	This refers to any time the science around “graphics” or “graphics processing” comes up—graphics in a more general sense describes in this context describes the science and technical work behind accelerating the processing required for creating and rendering images, animations, and video · *(Rendering)* This term within computer graphics is used to describe the process of generating a photorealistic or non-photorealistic image from a 2D or 3D model by means of a computer program-- the term "rendering" is also used to describe the process of calculating effects to produce the final graphical output · *(Shaders)* A shader in this context is a user-defined program designed to run on some stage of a graphics processor which provide the code for certain programmable stages of the rendering pipeline · *(Texturing)* Use of the term “texturing” or “texture mapping” in the context of graphics coded in terms of its relation to the process of applying of a type of surface to a 3D surface
Interactivity	This refers to (and is coded) every time an interviewee refers to this term in terms of the

Codes	Definition /Parameters Used to Apply Code to this Term
	user of a digital map or game map and how they interact with the digital environment or how the environment interacts with them
Military	Any reference to the "military" or the application of gaming/ geo by the military (particularly relevant in terms of modeling/simulation)
Navigation	Any references to how the user or player navigate through a digital map or game map
Peer Recommendations	The interviewee describes someone else who should be contacted that is in line with the subject matter/ set of questions that are associated with the thesis topic
SIGGRAPH (Special Interest Group on Computer Graphics and Interactive Techniques)	References to the SIGGRAPH Conference an annual conference on computer graphics organized by the ACM SIGGRAPH
Simulation and Modeling	Utilizing the term "simulation" and "modeling" as standalone phrases or together to describe the process behind developing and creating a digital prototype of a physical model to predict its performance in the real world
Spatial Data · Specific Data Type	The use of phrases "spatial data" or "geospatial data" is mentioned with reference to data that contains information about a specific location on a geographic surface · *(Specific Data Type)* A specific file format/data type mentioned in reference to the reference to spatial data.
Specific Gaming Companies Mentioned · Epic Games · Ubisoft	Every time a specific gaming company is mentioned--more specific coding is also provided if that gaming company's name comes up · *(Epic Games)* Mentions of Epic Games but not inclusive of mentions to Unreal Engine, the game engine created by Epic Games · *(Ubisoft)* Mentions of Ubisoft, a major gaming company

Codes	Definition /Parameters Used to Apply Code to this Term
Specific Geospatial Companies Mentioned · Cesium · Esri · Google Maps or Google Earth	The name of a specific geospatial company comes up (for example Bing Maps, Esri, Pelican Mapping etc.) · *(Cesium)* Mentions the use of Cesium products, software, or SDK · *(Esri)* Discusses the use of Esri product or brings up the use of ArcGIS
Specific Video Game Mentioned · Assassin's Creed series · Grand Theft Auto series · Minecraft · Fortnite · Roblox · Spiderman, NY	Mentions the name of a specific video game whether in reference to their personal preference, technical methodology, or as an example of principle the interviewee is describing · *(Assassin's Creed series)* Mentions the Assassin's Creed game series in any context · *(Grand Theft Auto series)* Mentions the Grand Theft Auto game series in any context · *(Minecraft)* Mentions Minecraft game in any context · *(Fortnite)* Mentions Fortnite game in any context · *(Roblox)* Mentions Roblox game in any context · *(Spiderman, NY)* Mentions Spiderman, NYC game in any context
Technical Advancements	Refers to instances in which the interviewee has mentioned either 1) A technical advancement that has changed their technical process/workflow in gaming or in geo or alternatively 2) they discuss how the arena has changed in its technical methods more generally from a historical perspective over time
WebGL (Web Graphics Library)	In this context refers to the JavaScript API for high-performance interactive 3D and 2D graphics

Table 3. List of Codes for Categorization in NVivo

These definitions were integrated into the codes inside the NVivo software system by adding them to the "info" section for each search term as seen in Figure 3 and Figure 4. For certain phrases such as the coded term "WebGL" seen in the NVivo screenshot that is featured in Figure 3, technical definition could easily be applied and drawn from the literature to describe this concept. The definition of WebGL, coded in this context describes the JavaScript API for high-performance interactive 3D and 2D graphics (Khronos 2021). However, in other cases, broader coded phrases for the NVivo analysis such as the term "Technical Advancements", as seen in Figure 4 refer to a specific question asked of interview respondents. Moreover, the definition featured in Figure 4 for the coded term "Technical Advancements" applies to not only this question but more generally to a technical advancement as it involves their process/workflow in gaming or in geo or can refer to how a particular arena has changed in its technical methods more generally from a historical perspective over time. In defining the codes and terminology, previous definitions in the technical literature were used.

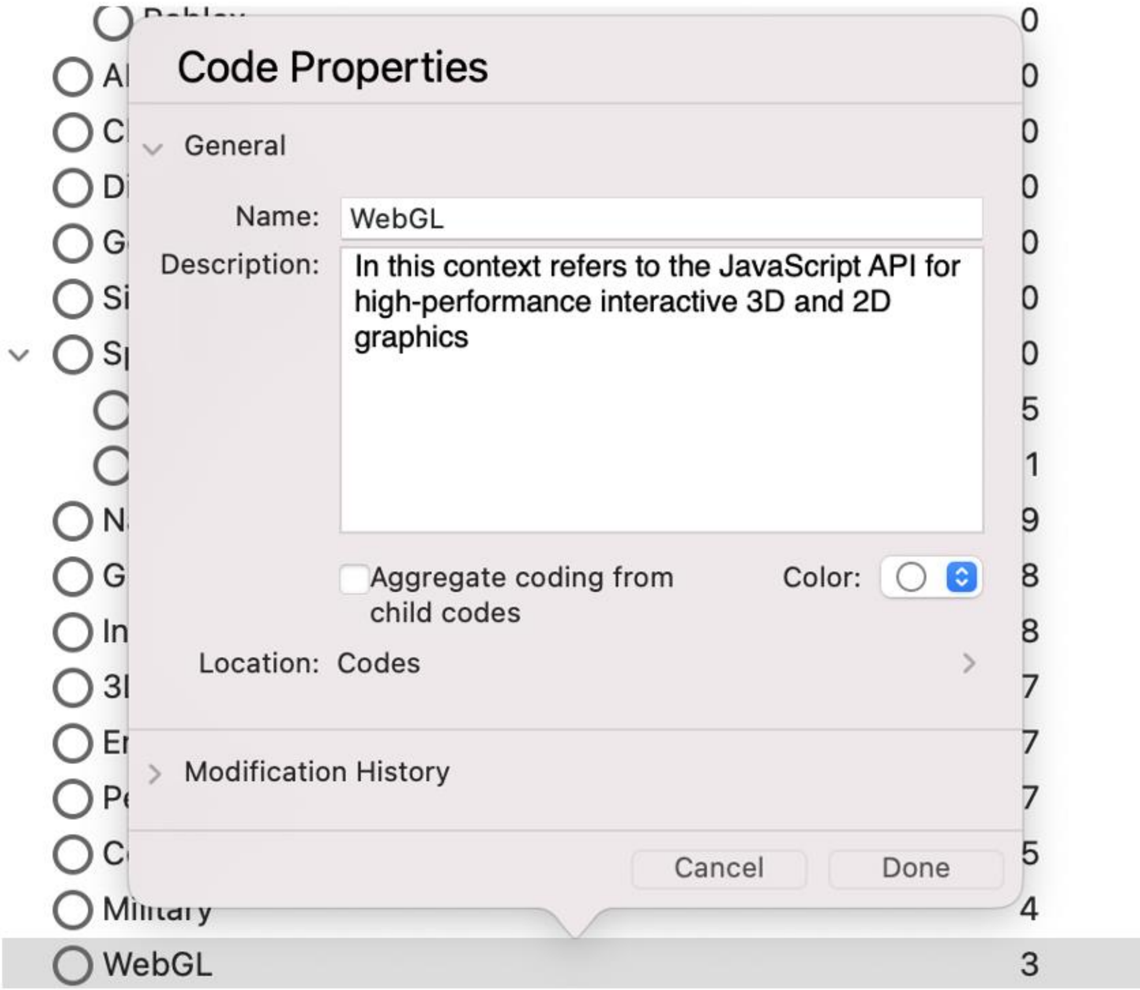

Figure 3. Technical code property technical definition in NVivo software platform

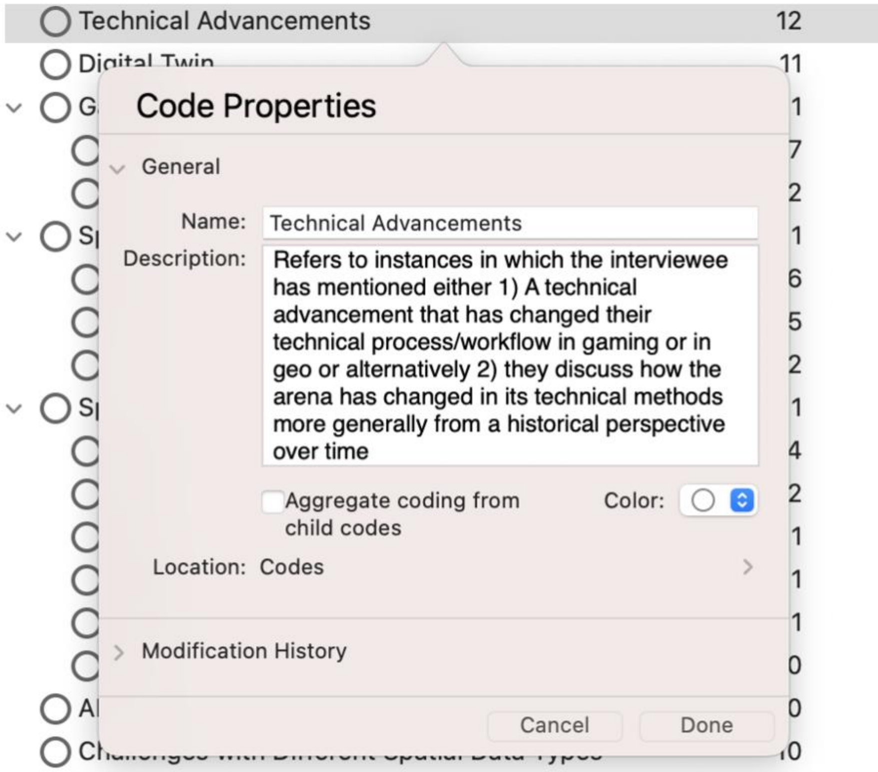

Figure 4. Code properties for interview-based terminology in NVivo platform

While the more question-specific terms required only a set of standard coded definitions generated specifically for this research (such as in the case of “Favorite Game Map " or “Peer Recommendations”), other terms required a more industry or academically accepted definition. “Dimensionality" in this case drew on references to the term within geospatial and video-game development literature defined in this coded study with reference to the dimension of user experience of a 2D or 3D spatial extent—more broadly this applies to the projection with the game interface of mathematical space within the user’s viewport (Mustaquim 2014; Jones et. al 2008). “Coordinate Systems' ' as a coded term to that end refers to the application of coordinates, to uniquely determine the position of the points or other geometric elements within an interface (Neteller 2008; Burenhult 2008). Further definitions of these broader more seemingly all-encompassing term definitions used other theses of a related nature to arrive at a definition to use throughout the qualitative codification process in NVivo for this study. In particular, How to Play with Maps, a graduate thesis by Ross Thorn (2018) focused on the extent and definition of "Interactivity" in game maps interfaces. Thorn's definition of game maps was applied in this study at length and drew on some of his drawn upon terminology to arrive at an understanding of "Interactivity" as the degree to which user of a digital map or game map and how they interact with the digital environment or how the environment interacts with them (Thorn 2018; Esposito 2005).

More technical definitions such as the use of the terms related to graphics or graphics processing drew on literature from computer graphics/processing space referring specifically to the science and technical work behind accelerating the processing required for creating and rendering images, animations, and video (Dunn 2011). The term "Rendering" within the context of "Graphics" as the larger header under which it falls in this context falls within the framework of computer graphics is used to describe the process of generating a photorealistic or non-photorealistic image from a 2D or 3D model by means of a computer program—the term "Rendering" is also used to describe the process of calculating effects to produce the final graphical output (Marschner 2021). "Texturing" within the banner of "Graphics" in this context is coded in terms of references to the term as it relates to the word "texturing" or the phase "texture mapping" in the context of graphics coded in terms of its relation to the process of applying a surface to an interface (Wei 2004; Marschner 2021). The final sub-header within the phrase of "Graphics" are "Shaders" which refer to a user-defined program designed to run on some stage of a graphics processor which provides the code for certain programmable stages of the rendering pipeline (Andersson 2007). A more traditional definition of "GPU" or Graphics Processing Unit was more easily defined from industry resources given that some SMEs interviewed in this study's place of work is Nvidia, a major GPU creator and provider to the general public and graphics community. "GPU" in this study is referenced and coded in terms of the part of the computer needed for high-intensity graphics processing (Owens et al. 2008).

The term "Military" is used as a coded term in reference to the application of geospatial or gaming/simulation by or for military purposes in services of the armed forces. Other terminology was driven both through literature from conference and academic resources as well as specific reference to technical terminology by the SMEs during the interviewees themselves. Among many of the military SMEs interviewed, the term "Geotypical" and "Geospecifc" is used by military personnel and coded in terms of "Geotypical" in which a simulated environment *looks* like a simulated geographic environment as opposed to "Geospecific" data which refers to modeled geographic surface which bears a one-to-one relationship with the environment it attempts to simulate. Further industry terminology coded for the analysis includes the coded term "Environmental Artist in Gaming" which refers to a specific role within a game development team tasked with the 3D modeling work to for an outdoor or indoor location of a game setting (Wyman 2010).

In addition to the more general lists of games or companies mentioned, a separate set of codes for these three terms was also laid out in reference to the major overarching codes listed. 2-6 examples were listed on each and coded sedately with their own set of codified references. To provide a set of examples of these highlighted search terms among these three overarching codes, in the case of the code "Specific Video Game Company Mentioned", there were seven gaming companies listed in total by respondents in the qualitative research with SMEs for this study, but two companies in particular (Ubisoft and Epic Games) stood out as the most referenced and the most aligned with the line of questioning used for the study as a whole. As a result, in the case of the code “Specific Video Game Company Mentioned": these companies were given their own separate code under the larger header of “Specific Video Game Company Mentioned”.

With this revised codebook in hand, a full coding was conducted of all the interviews that comprised this study (16 SMEs total). Reliability analyses conducted after this full coding indicated strong percent agreement (i.e., the lowest percent agreement for an individual code was 92.35) across the entire dataset and an overall Kappa value of 0.61, which has variously been described as “good”, “moderate”, or “substantial” agreement (Cohen 1960; McHugh 2012). This indicated that sufficient agreement, from the first to the second coding of the interviews, about whether each chunk of text in the interview did or did not contain the themes (codes) of the codebook (McHugh 2012).

Having established reliability in the coding of all the interviews, a thematic analysis of the interviews was conducted next. NVivo was used to view all the instances of each code, one at a time, which allowed summarizing and analysis of the content for each theme (Chapter 4: Results). Several analytic tools contained in the NVivo software itself were also used, in alignment with literature from similar types of qualitative research using NVivo’s software. Across all analyses of the qualitative findings from these interviews, a coefficient of agreement for nominal scales was applied drawing on the methodology spelled out in (Cohen 1960).

Chapter 4 Results

Eighteen in-depth interviews were conducted with SMEs in academia and industry from the geospatial and video game development domains. The results of the analysis and investigative research are broken down broadly into recurring themes across the conversations with a broad swath of industry leaders, developers, and technologists. These were coded with the software package NVivo. Following this initial narrowing of themes, the investigative analysis with these SMEs was then bucketed into shared challenges between these two arenas. Using a Kappa Alpha Frequency test, the extent to which the SMEs brought up these shared themes is described in detail, as well as the degree to which interviewed SMEs agreed on the shared challenges within their technical methodology. Finally, the third level of analysis focused on parallel concepts across the codified transcripts through a Kappa analysis of frequency.

4.1. The Geospatial and Gaming Relationship

References to the term "Geo and Gaming Relationship" were analyzed for frequency across SMEs interviewed for this study (Table 4). This code applied to references in which SMEs discussed their views on where they see the current status of the relationship between the geospatial and game development domains. This was largely in the context of their answers to the question listed for both geospatial or gaming SMEs "*How have you come to understand the relationship (if any) between the geospatial software development and gaming fields?".*

Respondents gave two types of responses. Some SMEs spoke to the technical methodological exchange between the two domains whereas others responded with broader takeaways on the state of play between the two fields. Much of the qualitative analysis process

Interviewee	Coverage
GeoA_1	2.05%
GeoA_2	4.20%
GeoI_1	3.19%
GeoI_2	15.23%
GeoI_3	5.00%
GeoI_4	11.39%
GeoI_5	3.31%
GeoI_6	9.08%

Table 4. Frequency of Geo-Gaming References by geospatial interviewees

centered on the points of described intersection across specific codified terms from files within NVivo classified for a geospatial SME vs. a gaming one. The two most notable examples of the connection between the geospatial and gaming arena in terms of software development and the exchange between these two arenas is described by GeoI_4, a former software engineer at Google Geo whose work within the graphics processing domain allowed technical insight into the workflows behind both spaces. GeoI_4 describes that:

"…I think in terms of the literal and obvious overlap of companies that are doing both, or people that are in both spaces…like a Microsoft Flight Simulator or Pokemon Go. You have to have a pretty good understanding of both contexts to build something like that. I think in terms of the techniques that come to bear and the technologies that play into that from primitive stuff like graphic CPIs, up to the spatial indexes and the data structures and algorithms that are useful, I do feel like there's a lot of overlap." (GeoI_4)

GeoI_4 spelled out some of the techniques that have proven valuable to both spaces from the extent to which CPIs (Cycles per Instruction) and the science behind quickly processing information such as geographic data types within both a geospatial and a gaming software development context (Jeffers 2016). Moreover, the process of storing this data, known within the geospatial domain as spatial indexing, was described by this SME as a shared complexity and knowledge base for both spaces (Hörhammer et al. 1999). The Microsoft Flight Simulator and Pokemon Go, discussed in terms of their historical ties as prime examples of geospatial and gaming exchange in Chapter 2 of this study, were brought up as central examples of the intertwining of the two spheres. VGI_5, an interviewee whose professional ties to the subject are attributable to his professional position at Epic Games, spoke to the technical evolution and blending between the two "lanes" and expounds upon an awareness and recent trend toward to the two spheres gradually coming together:

"…the two lanes have crossed paths, I think quite a bit…as the gaming and simulation has crossed paths with the geospatial lane, geospatial has sort of seeing, hey, we could make our geospatial stuff look better. If I want to visualize my data in an engine, again, the real power behind most game engines is that they are just really good at very efficiently visualizing data, whatever that happens to be. And so geographic data is just a bunch of data, and if you've got an engine that can render that very effectively, very efficiently, why not? And have it look good. And so again, the video game companies have sort of already tackled all of those problems of running in an optimized way, running in an efficient way. Then it's just a question of what data, what thing am I trying to visualize? And so I think that's why geospatial environments have started more and more to adopt game engines as well, or utilize game engines as sort of a visualization front end." (VGI_5)

Respondents, including VGI_5, often brought up the inclusion and rendering of large or unwieldy geographic data, and its ability to be easily immersed and worked with inside of game engines. Respondents often spoke to the use and ease provided through the utilization of game engines (the coded term and use of the term "Game Engine" is detailed below) in working with large geospatial data sets or imagery files. The capacity of modern game engines to import vast quantities of geographic data has only risen in popularity by technologists in both the geospatial and gaming spheres. Two of the SMEs whose description fell within the coded term "Geo and Gaming Relationship" were GeoI_1 and GeoI_2 (as displayed in Table 4). This is likely due in part to the fact that GeoI_1 and GeoI_2 both come from Cesium, a popular open-source software platform for displaying 3D geospatial data.

The foundations of Cesium, which has grown to become a behemoth within the geospatial industry, trace their origins in part to the technical methods used by gaming professionals and graphics engineers. To start, as GeoI_1 explains it:

“So in the early days of Cesium we built Cesium JS as a bespoke rendering engine, Javascript and Web GL. I mean, I wrote the original rendering engine for it. As time went on, we saw that there was a huge opportunity to take game engines and to kind of geospatial enable them if you will. And then we got interest through the use of 3D tiles and the army one world terrain program and people were like, "Well, we kind of want 3D tiles everywhere." Right? Not just in Cesium JS. And that's when we started working with Epic Games.” (GeoI_1)

This history of Cesium as a company and the tie-in between the two fields speaks to the degree to which major geospatial companies report similarities between their domain and the technical aspects of game development. The collaboration described between Cesium and Epic Games, companies which represent leaders within the geospatial and gaming industries respectively, speaks to the degree to which industry leaders and technologists describe one another to advance their technical workflows and progress. In pulling together the qualitative data into grouped codes, designation was given to Cesium and other major geospatial companies like Cesium with its own codified term for “Specific Geospatial Company Mentioned” to then run a frequency test on how many times that company was discussed by technologists across the two domains. The analysis conducted with regard to this coded term pertained both to the number of times a company was mentioned as well as which SMEs within the geospatial domain (whether they be industry or academically inclined) discussed a particular concept. This coded term and its definition and use will be discussed in further detail below.

For three specific coded phrases 1) Specific Geospatial Company Mentioned, 2) Specific Video Game Company Mentioned, and 3) Specific Video Game Mention, a further breakdown of the answers provided by the SMEs during their interviews was recorded and analyzed in this study (Tables 7, 8 and 9). The full set of coded terms in this qualitative study which were given individualized sub-headers underneath their larger banner includes “Graphics”, “Game Engine”, and “Spatial Data”. By creating these sub-headers, coded terms could be broken down into a more specialized group underneath its larger header as a point of reference. This provided a means by which to study the search terms as mentioned by the SMEs interviewed within the context of a larger code.

Name	Files	References
Specific Video Game Mention	11	57
Spiderman, NY	1	4
Roblox	0	0
Minecraft	1	2
Grand Theft Auto series	4	8
Fortnite	2	6
Assasins Creed series	1	4
Specific Geospatial Company Mentioned	11	64
Google Maps or Google Earth	5	25
Esri	2	7
Cesium	6	31
Specifc Gaming Company Mentioned	10	43
Ubisoft	1	6
Epic Games	5	11
Spatial Data	12	60
Specific data type	11	63
Graphics	12	82
Rendering	11	83
Shaders	3	7
Texturing	8	43
Game Engine	11	42
Unity	2	4
Unreal Engine	7	34

Figure 5. Sub-headers used in codified list of terms

In looking at the most frequently applied code within the qualitative analysis, the "Geo-Gaming Relationship", more than any other interviewee, GeoI_2 spoke with the greatest degree of frequency and depth with regard to the "Geo-Gaming Relationship" (as seen in Figure 6) from a geospatial orientation. GeoI_2 describes this coded term in full in summarizing the connection (in addition to this intersection's connection to Cesium as a whole) in explaining:

"I think there's so much synergy between the geo and gaming communities. And in some ways I kind of describe my personal journey and Cesium as applying computer grains and computer graphics techniques to geospatial problems, right? And we fundamentally look at 3D geospatial as a computer graphics problem, the same way that, someone developing tools for a movie or for a game looking at something as inherently 3D. So anything that's around spatial subdivision that's being used in games and movies, I think applies very well to the geospatial world. We also see the game engine starting to come of age, doing really high precision, large scale rendering. Right. Which I think is also very relevant to the gaming community or to the geospatial community. And then likewise, as seen in the gaming world, they develop very sophisticated content pipelines, right. To take kind of raw data through to the final source for delivery. So there's a ton of synergy in both directions." (GeoI_2)

Similar to VGI_5's point, GeoI_1 saw a parallel in the adoption of the game engine to help take in and work with heavy-duty geospatial datasets. The trend described by VGI_5 and GeoI_1, both of whom spoke with the greatest degree of frequency to the code "Geo-Gaming Relationship" (Figure 6 and Table 5), also make repeated mention to advancements in the field of computer graphics as helping accelerate the adoption of corollary methods and direct exchange between the geospatial and video game development arenas. Geospatial technologists seemed to expound upon this intersection between the two domains the most. This points to a wider and perhaps more recent awareness within geospatial software development in looking at the methodology of game developers for technical understanding and insight.

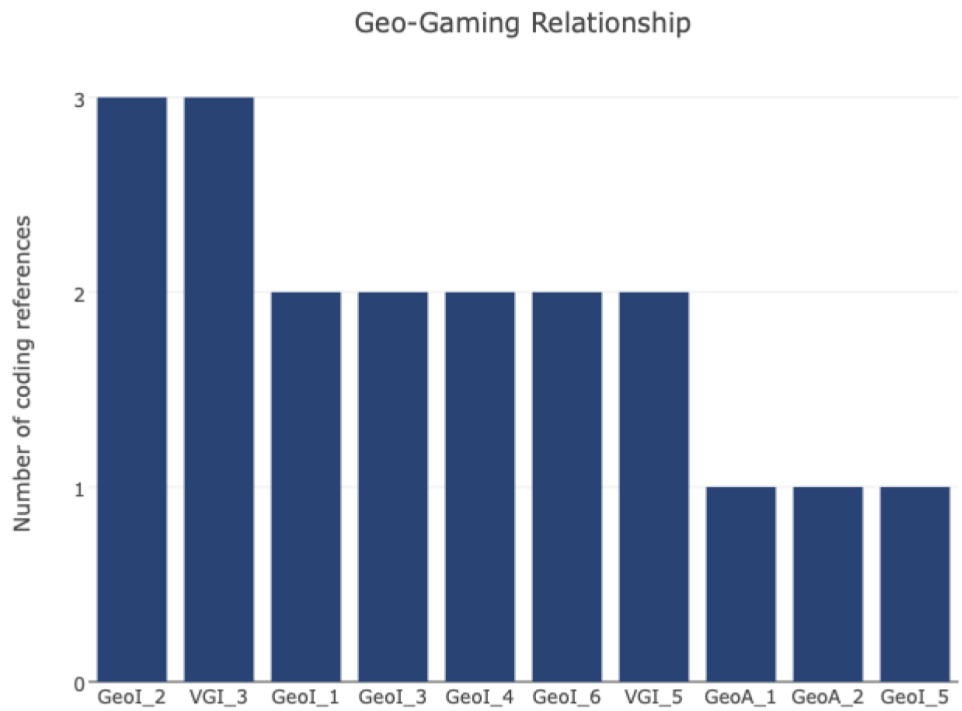

Figure 6. “Geo-Gaming Relationship” references across interviewees

Name	In Folder	References	Coverage
VGI_3	Files	2	4.52%
VGI_5	Files	2	6.64%

Table 5. References to Geo-Gaming Relationship from VGI_3 and VGI_5

4.2. Simulation and Modeling

The coded reference to the term “Simulation and Modeling” was defined as the process behind developing and creating a digital prototype of a physical model to predict its performance in the real world (Carson 2004). The definition is drawn from the literature surrounding the process of simulation within both a geospatial and a gaming-derived context (Zyda 2005; Crooks et al. 2012).

4.2.1. Simulation and Modeling in Coded Reference

The connection between the technical methodologies within the geospatial and game development spheres is the arena known as simulation and modeling in the technical community. Individuals in the simulation and modeling space make use of traditional game development procedures such as graphic processing/rendering algorithms, and draw on methods employed by traditional entertainment-based game development creators and developers. Simulation software developers also employ the methodologies of geospatial developers in incorporating 3D data into modeling environments. Simulation and modeling professionals tend to understand themselves at the center of video game development and geospatial software development. For the purposes of this study, simulation and modeling is treated as similar to game development (Chądzyńska 2008; Crooks et al. 2016). In many ways, simulation and modeling represents the melding of the geospatial and game development domains. As VGI_1, a developer at Amazon Lumberyard, Amazon's bespoke game engine platform, put it:

"…this research isn't necessarily specific to video games and probably isn't called that because, yeah, even now it's probably a little harder to get attention in the academic world if you call it video game versus interactive simulation or metaverse or anything else pretty much." (VGI_1)

This blending of the nomenclature in terms of simulation and modeling demonstrates the melding of geospatial and game development. Many industry and academic respondents used the terms "simulation and modeling" interchangeably with GISci and gaming research/commercial spheres. The degree of frequency with which individuals in both domains spoke to the connection between geospatial and gaming is seen in Table 6.

Name	References	Coverage
GeoA_1	15	73.45%
GeoA_2	2	10.32%
GeoI_1	2	5.27%
GeoI_3	15	41.74%
GeoI_6	1	10.69%
VGA_1	1	5.68%
VGI_1	3	39.15%
VGI_3	2	5.24%
VGI_4	9	52.37%
VGI_5	10	62.39%

Table 6. Percent coverage of references to “Simulation and Modeling”

Modeling and simulation and its corresponding research and community provides a means by which to allow the two domains to meld and meet in terms of technical implementation and exchange. The major point of connection in recent industry trends has been the adoption of processing and simulating real world environments found on earth. As GeoI_3 explicates in terms of the technical methodology drawing on the two spheres necessary for simulation and modeling:

“You need to load terrain or levels as they often call them in the games world...Our requirements from the beginning because we do real-world simulation has been real-world data, so geospatial data. It's funny. More recently, I think some of the game engines are starting to support true geospatial data, and bring them in, and do whole-earth kind of stuff. That's a relatively recent development. I think historically, in the games world, the focus was on creating tools to allow artists to create fantasy worlds, to easily create worlds that don't exist. Whereas, like I said, in our space, it was always about loading real-world stuff.” (GeoI_3)

The adoption and processing of large-scale geospatial datasets for the purpose of modeling and simulation has led to the adoption of game engines to simulate this data, providing a means of exchange between gaming and GISci. This connection has become imperative within the non-entertainment-based gaming/simulation world as real world geographic locales and situations increasingly use traditional spatial datasets and spatial indexing methods to create hyper-realistic environments. VGI_4, an executive at Nvidia, a graphics processing and AI industry leader, details the power of this connection (Brodtkorb 2013; Schaller 1997). VGI_4 describes the importance of and outlines the technical methodology behind this process:

"We now have all of the ingredients to construct a simulation of a whole world. These virtual worlds. And that's extremely powerful. Once you can simulate a world, you can make that world visible or available to the senses of some human. We gain some superpowers. If you have a perfect simulation of a world. And if you had infinite computing power, and all your algorithms are perfect, and you can simulate everything perfectly, and you can ingest the real world, you can convert it, through computer vision, or other similar algorithms into a representation of that virtual world, you essentially get teleportation." (VGI_4)

The ability to transpose real-world geographic data into the game engine provides breakthroughs for the modeling and simulation world as well as the geospatial arena. The rise of computer processing power and artificial intelligence further drives the connection between the two domains and the necessity of these two fields to draw upon and exchange technical methods.

4.2.1.1. Coded References to Digital Twins

As described by GeoI_3 and VGI_4, the adoption of geospatial and game-development based data storage and processing methods was driven by the desire of environment simulators to accurately depict real world geographic locations. The movement toward this is known within the research found on both sides of the divide as a "Digital Twin".

"Digital Twin" is defined as a term that is coded in reference to a virtual representation and serves as the real-time digital counterpart of a geographic location, physical object, or process (i.e., cases in which a city in which a video game is set which is modeled after a real-world city (NY, Athens etc.). For the purposes of this study, the term "Digital Twin" can also apply to any modeling within a video game world is meant to represent the real-world environment generally (not necessarily a specific city could also be a place, mountain, general region etc.). The definition of the term "Digital Twin" has been a longstanding component within the research and literature on the connection between the gaming and geospatial arenas (Dumaresq 2018; Jacoby et al. 2020; Ketzler et al. 2020; Mackrell 2021). The connection is the desire of researchers in both these spaces to develop "Digital Twins". The connection in this study between the two coded terms can be seen in Figure 7, which demonstrates the major points of intersection within the geospatial and gaming realms.

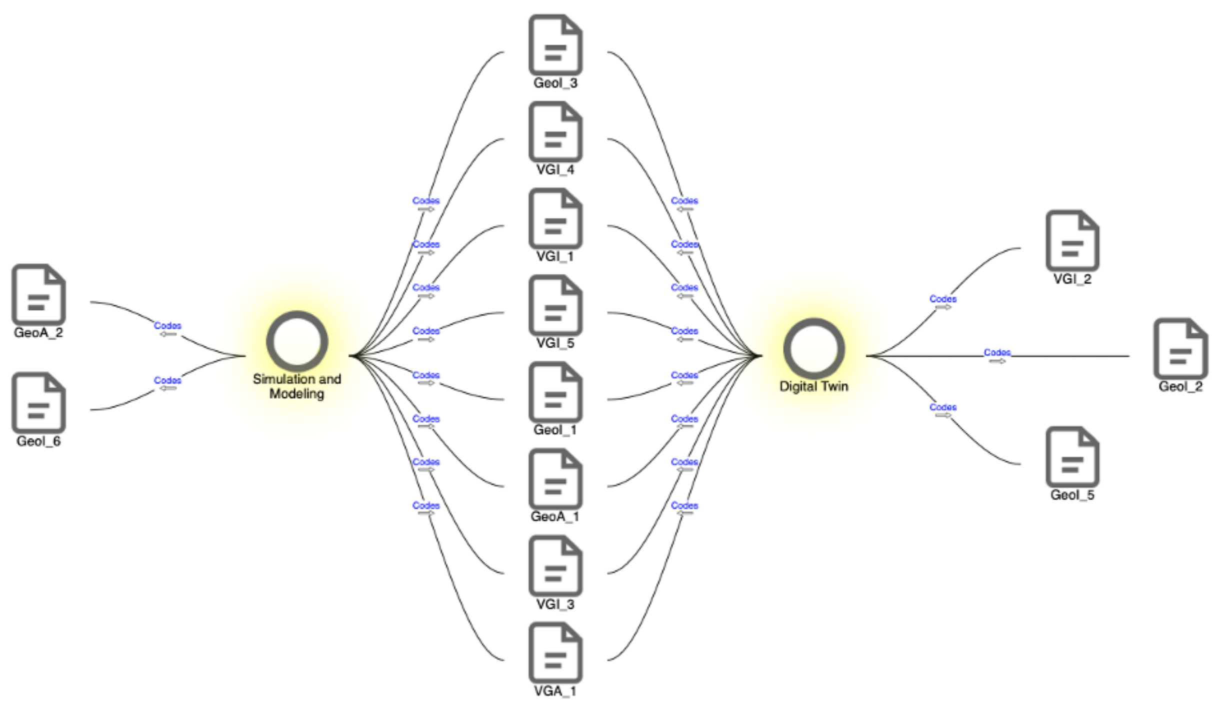

Figure 7. Mentions of "Digital Twin" vs. "Simulation and Modeling" as a coded term

The term "Digital Twin" is described with the SME interviews using the perspective of a real-world twin as a reference for the use of this terminology. GeoA_1 expands upon the exact definition of a digital twin in comparison to the common parlance associated with a twin in the biological sense to provide perspective on its use within simulation and modeling arena:

"…So when I think of a twin, you can have the biological twin, they look a lot alike. They often are dressed the same way. They have the same color eyes, the same color hair, or the same facial attributes, the same body shape. Parents often dress them the same way. So now they have the same clothing and you look at them. And so on the surface, they look the same. So that would be the example of the exterior collection that we're currently doing. But in the end, everything on the inside also matches pretty well too. So they have many of the same mannerisms, tastebuds, vision, interests, emotion, habits—down the list. That's all internal. A digital twin is a real twin when you replicate everything from inside to outside, and then how it often interacts with the environment around it. It's quite close. So I think of this and I say, well, in order for it to really be a digital twin, you have to be able to measure everything or have a way of replicating everything about it. So a digital twin would actually take the real world and then it would replicate it, not just on the outside, but on the inside as well." (GeoA_1)

Significant points of connection for the discussions held with SMEs from the gaming and geospatial communities for this study often revolved around the simulation of real-world space into gamified or simulated environments. To do this the gaming industry has drawn on increasingly common technical workflows and data sources to recreate real world objects in geographic space (not just cities themselves) all of which are encompassed within the terminology "Digital Twin". This trend toward drawing in real world data can oftentimes be tied to a specific object within geographic space. VGI_3 draws on the example of Mt. Eiger as an example of the process behind creating a digital twin off a real-world landmark:

"…what's interesting within the games industry is that what I know is that they very much are doing it not to be realistic, per se. I mean, realistic in the sense of, yeah, I'm looking at what hopefully looks like a realistic mountain, but it's not like, oh, that's definitely Mt. Eiger, or whatever…people are grabbing data and trying to make realistic worlds. I mean, I've seen that with just some applications where they'll kind of pull something in and go, 'Okay, I got the mesh and let's go and see what's going on.'" (VGI_3)

While geospatial developers might have already relied on traditional spatial data sources in their work, streaming the data into this environment became an incredibly important aspect within the technical methodology of game developers that geospatial developers have taken on for their own. GeoI_1 describes the desire on the part of game developers to draw-in and learn from the resources that were traditionally created for the geospatial community:

"…folks had a need for this global scale, high fidelity real world visualization tool set….And having that stream to then put in the real world trade imagery, I just thought it was so cool and really opened up our eyes to the breadth of use cases we could serve." (GeoI_1)

The necessity and corresponding desire to incorporate high quality global datasets of the world unlocked powerful and novel possibilities for the geospatial community in unforeseen ways. In partnering with game development companies, geospatial datasets and software development toolkits found wholly new use cases within the gaming space in recent years (Kim et al. 2018). The process of creating and developing a digital model of space, developers on either side of the divide have attempted to recreate whole cities. Such is the case in terms of the Spider Man, NY game, the developers for which attempted to create a world that bears a direct relationship to New York city. GeoI_2 describes the detail to which game developers attempted to recreate every tiny detail of the New York cityscape:

"…being able to walk from your apartment as Spider Man, Miles Morales, or anybody, to Central Park exactly as you do in real life. The gap between what we have currently enabled through somebody like Insomniac and somebody like Cesium is actually right in front of us. We're just not closing it. If you've ever been to New York or you're familiar with it, there is, because it's just the color palette of our buildings the like, there is a light refraction and reflection phenomenon that occurs that gives our just general, let's call it air, a particular feel and color and tone and density. And that was really what they went out of their way to capture, as well as making sure that certain really unforgettable and of course critical landmarks, and a relative, let's say, capturing of distance. New York is very interesting, because it's fairly easy to navigate. You can almost always look up and kind of orient yourself north, south, east, or west. Plus, we have the benefit that our streets are just numbers. It's fantastic. They did a lot of that. They're beginning to touch upon some of the insights that geospatial already actually has for us. We just haven't connected yet." (GeoI_2)

The high-intensity detail-oriented landscape in which the Spiderman, NY game takes place presents numerous lessons for the geospatial arena. Components built into the digital twin version of the city such as the processing needed for navigation, orientation, and albedo remain important technical examples from which geospatial developers can draw from. By developing a city that looks exactly like the city of New York in game-space, these technologists help lay a framework from which geospatial developers can draw from methodologically. VGI_1 spoke to yet another example of the digital twin in game development in other similar such games:

"So you have your games like GTA San Andreas or wherever or Ghost Recon Wildlands. And so these games that take place in real world settings, for the past several years, have been starting with DM data and satellite imagery as their base terrain data to the best of my understanding. There's some GDC talks around it, and it's definitely what it sounds like they've done. And so there's already been a history of this. And then even on the fantasy side, if you've heard of a game called Horizon Zero Dawn, it's a PlayStation game fantasy world that takes place in distant times. But the world that that's based on is I believe it's Boulder, Colorado. And so again, from what I've gathered, they started with satellite data, satellite imagery to build out their base terrain for their world. And so it has all of the contours of Boulder, Colorado, even though it doesn't have the actual present day city in it." (VGI_1)

VGI_1 brings up the examples of GTA V's San Andreas landscape which was built with the specific aim of creating a digital twin of the city of Los Angeles. While, in the case of Rockstar Games GTA V, much like the GTA: Vice City which mimics the style and urban landscape of Miami but doesn't directly represent the same spatial representation and makeup, GTA V described by VGI_1 is meant to represent the city of Los Angeles. Moreover, VGI_1's other two examples Ghost Recon Wildlands and Horizon Zero Dawn do not directly correlate but do present a semi-accurate digital twin representation of Bolivian cityscapes and Boulder, Colorado respectively. The representation and mention by SMEs to the coded term "Digital Twin" was referenced beyond earthbound digital mimicry of space and environment. VGI_2, a software engineer and industry leader within an independent game studio called Disbelief Games, describes how the methodological processes that have made use of geodata to create a "Digital

Twin" as defined in this study go well beyond solely terrestrial bounds. VGI_2 spoke specifically about an example in his own work drawing on geospatial data to create a Mars-based game experience:

"…we did a project about three or four years ago for a company…a VR Mars experience. It was called Mars 2030 and I think that was the project we did with perhaps the most overlap between what geospatial companies do. We took geo data from the Mars Reconnaissance Orbiter, the HiRISE satellite data, and we recreated 40 square kilometers of the Martian surface in game, which you could then observe in VR and so, the starting point there was it was photogrammetry for some of the high detail rocks and this satellite data." (VGI_2)

By drawing upon these geospatial datasets, not only on an earthbound level but from photogrammetry and satellite data (data sources often made use of in geospatial software development), game developers such as VGI_2 have found success creating representations of extraterrestrial environments and landscapes. VGI_2's specific mention of real-world (or in this case real-Mars) terrain generation through the inclusion of satellite imagery resources from the Mars Reconnaissance Orbiter laid the groundwork for more accurate digital creation of space such as that example seen in the Mars 2030 game. Much can be learned from the geospatial and game development world as game developers come to understand the value and benefit posed by creating digital recreations of real-world locations. The push towards creating a "Digital Twin" as referenced by geospatial and gaming SMEs alike helps to lay the groundwork for further technical and methodological exchange between the two communities.

4.2.1.2. Geospecific vs. Geotypical Terminology Coded Reference

As the rise within geospatial communities in drawing up and learning from the game development spheres to develop digital twins, an important distinction must be made in reference to the terms "Geospecific and Geotypical Data". The distinction between these two terms and discussion between the use of data of both types to determine digital representations of space and the degree of correlation the composition and makeup of a given environment lines up with a geographic area. These terms are defined as geospecific vs geotypical data by GeoA_1:

"Well, to me, where the clear line of departure has been, and I think we're closing the gap to where we're actually finding that there maybe doesn't need to be a gap anymore, but there was a gap and the gap was the words I've used, not just me. There's others have used these words too, are geotypical and geospecific data. So geotypical data is data that is synthetic. It looks like, it feels like, it smells like the real thing. But in fact, it's just a dataset that has been built in some local coordinate system. So what I would call a game space, that has a 000 center somewhere, and then everything revolves around that local coordinate system. And then it gets ingested or used inside of a gaming engine. Then there's geospecific data, which is real world data connected to a real world coordinate." (GeoA_1)

The differentiation between geospecific vs geotypical data, as described by GeoA_1 describes data that 1) spatial data that bears a 1:1 coordinate relationship between the environment being digitally represented and 2) spatial data that resembles the same look of the location being represented but doesn't match up in ratio to the environment depicted. A GIS system, for example, distinguishes itself as a software system that can accurately give a sense of the coordinates and dimensions of real-world space. A game engine, on the other hand, might rely upon geotypical data to help depict a game environment. Recent collaborations to join traditional gaming and geospatial Software Developer Kits (SDKs) has led to advancements in bringing the geotypical data displayed in a game engine to more geographically realistic and coordinate specific terms. Geospatial companies such as Cesium have, in the last few years partnered with major gaming companies such as Epic Games to bring geospecific data into popular game engines such as Unreal Engine (the proprietary game engine created by Epic Games). Other such collaborations such as major geospatial software companies like Mapbox collaborating together with the world's most popular game engine in use, Unity, similarly seeks to draw upon real world environments and terrains available when incorporating geospecific real world data into a game's setting (Mat et al. 2014; Laksono 2019). Other game engines have pursued similar partnerships to bring geospecific data into their platforms. For example, Unity, the world's most commonly used game engine, recently partnered with a major geospatial industry leader, Mapbox. This point of connection between the geospatial and gaming software development communities has provided for a further delineation between geotypical and geospecific data within exchanges between these two communities.

The relationship shared between geotypical and geospecific data represents a trend toward the melding of technical methods between the gaming and geospatial spheres to go beyond the mere representation of digital cities and environments with geotypical data and to instead depict real world space with geospecific data. In describing this trend VGI_5 explains:

"So geospatial data and simulation, so keeping games out of it for a second. They've sort of grown up kind of in parallel paths where geospatial applications, geospatial software, was very much geared towards the categorization and organization of geospatial data so you could do analytics on it or you could use it for whatever your purposes were. Simulation has grown up saying, "Hey, I want to simulate the world to some extent." And as more and more data has become available, simulations have said, "Well, why don't, instead of simulating in a made up place, instead of saying, 'here I'm just some random not realistic location,' why don't I take that geospatial data and simulate where I'm actually going to go operate." Whatever that operation happens to be." (VGI_5)

The move to represent real world space ito represent the world with absolute coordinate accuracy has pushed GISci and gaming worlds together. No longer is geotypical data (data that resembles a location but does not depict every element of its geographic composition) enough for game developers. Similarly, geospatial developers can learn from the desire of game developers to create digital twins to present dynamic detail-rich products that are common to game engines and their associated output.

4.2.2. Military in Coded Reference Within Modeling and Simulation

The coded term “Military” occurred both within the use cases for modeled and simulated environments, and the background of those within the modeling and simulation or gaming space. This can be understood in part because of the military’s desire to represent as an environment realistically to help train soldiers for warfighting scenarios. Creating a geospecific environment is an essential piece of modeling and simulation within this type of use case. GeoI_3, an executive within Mak Technologies, an industry leader within the modeling and simulation space describes the importance of geospecific data for simulation and modeling for military use cases:

“We do modeling and simulation software, so building 3D virtual worlds and doing simulations in them primarily for the military simulation space, people who are building flight simulators and first-person shooters, but for the purpose of training soldiers rather than entertainment mostly. We do some stuff outside of defense, but it’s mostly defense work. It’s all kinds of stuff. It’s simulations for all domains, for driving, for ships, for planes, for helicopters, satellites, whatever.” (GeoI_3)

Military training has found a consistent need to represent the world using geospecific data to help train soldiers for the battlefield in as close to a mirrored environment as possible. The importance of geospecific over geotypical data cannot be overstated, given that proper training for soldiers within a gamified simulated space can truly be a matter of life or death for soldiers, insurgents, and civilians.

Many of those within both the geospatial academic and gaming industry spaces traced their origins to the Military within the coded reference “Career Connection to Thesis Subject”. To some, the modeling and simulation community provided a critical example of geospecific data usage in a gamified environment. Pushing the typical specifications of an entertainment-based video game, the modeling and simulation community specifically requires accuracy to the highest degree to ensure that soldiers are trained in an environment that accurately reflects the scenario they may be placed in on the battlefield. GeoA_1, former military who has now moved into the geospatial academic community, has worked within the modeling and simulation community the entirety of their career. The evolution into modeling and simulation came from the desire to push the bounds of technical advancement from a paper-based format to 3D interface to improve accuracy in warfighting efforts. GeoA_1 spoke to his own connection to this changeover in military preparation:

"…[GeoA_1] ended up being assigned to the unit that was developing all the new technology that the army was eventually going to adopt. This was the fourth infantry division. And they were the ones that were doing all the new digital mapping and the integration of digits into the United States army So they went from an analog force, paper stuff, paper reports, all of that to a digital force. And as part of that, there was a whole bunch of digital mapping that was being done. And the digital mapping was to start with, it was all 2D space. So like 2D data. And then eventually it became something that we needed to address with 3D data and then enter the need to use 3D data in order to do things like modeling of simulation type systems. You have to have 3D data in order for that to work. We really weren't thinking about that at the time, we were just actually thinking about the new technologies that were going to use this kind of data moving forward. And so as you probably can appreciate where a lot of the money in the technology development came from, this was government money that was building these systems that were being used by Department of Defense." (GeoA_1)

Movement from a technical perspective from 2D to 3D interfaces to train warfighting endeavors is described by GeoA_1. The relevance of the "Military" as a coded term is significant because the need for highly realistic environments in game space has forced ever-inventive ways of digital modification to geotypical as opposed to geospecific instances. In 2018 alone, the Department of Defense (DOD) spent $2.4 billion in service of modeling and simulation tech (Harper 2019). The source of revenue for simulation-based expenditures has been driven by the military and is worthy of note in terms of the backgrounds of respondents from the sector interviewed for this study. This also supports the move to create geospecific systems to display gamified environments and spatial data. In describing the move towards incorporating the strategies of geospatial technologists to develop more and more realistic depictions of external environments. The hyper realistic training environments are beneficial for the user in a warfighting or entertainment-based scenario. As GeoA_1 describes it:

“I think of it as interaction where you're interacting with the data in a much more robust way than just visually looking at it. So, most of the systems that you see right now that you interact with have connections to sight, what you see, so a mapping application or a 3D visualization.” (GeoA_1)

The introduction of 3D environmental systems to depict a given environment has numerous advantages in the entertainment-based gaming and military modeling and simulation spaces. Together, the combination of military and entertainment-based advancements in gaming in these two fields have helped serve as a conduit for advancements for the GISci data. The necessity to rely on geo-data allows for the blending of visualization methodologies for all parties involved, spurring the general advancement and f exchange between these spheres.

4.2.2.1. Environment Artist in Coded Reference

The desire to create hyper realistic environments is met with in the gaming space the emergence of the role of the “Environment Artist in Gaming”, a coded reference utilized by SMEs in this study to describe an individual on a game development team tasked with adding detail and texture to the game environment. The modeling and simulation worlds, in collaboration with the geospatial arena, create hyper real environments, has made an impact on the gaming space and this role specifically within the gaming space. VGI_2 explained the impact of modeling real world environments with an eye to absolute accuracy in recreating a location such as in the case of a digital twin or digital city. VGI_2, describes the historical trend within the technical methodology of software developers in the gaming space:

“So, the thinking is that this will open the door to more photogrammetry being used and a lot of companies are pondering what that means for them because traditionally, you have environment artists who make stuff and then lower designers who put the stuff together to make an environment, but maybe our industry is going towards virtual sets where you actually make a set and then scan it instead. Now, obviously that would only be for the high end games at the moment at least because not everyone has a sound stage or whatever. But there is. The technology to process those large amounts of data is coming along all the time, both in terms of dealing with a massive data import and also being able to render large quantities of data at run time.” (VGI_2)

VGI_2 reflects the industry trend of moving away total reliance on environmental artists within the game development space toward bringing in real world data to provide the most accurate depiction of the chosen game-space. The development of high-quality game engines, described by many of the other SMEs interviewed for this study, represents a trend reflected within the gaming industry cohort. Geospatial technologists at the academic and industry level spoke to this trend in reflecting on the results of respondents. GeoI_3, elaborated on the benefits of geospatial data to help simulate and model environments. The inclination towards creating pixel by pixel encapsulations of real-world space has ushered in substantive change in the geospatial arena as well. GeoI_3 spoke to this phenomenon within the output and product of Mak Technology’s work:

“The grass will blow in the wind, and you can probably see there. The point is no artist said, "Hey, let's put grass there." We just loaded the source geospatial data that said, "That area..." That was literally a land-use raster map. It was a texture that tells us on a per-pixel basis at some resolution. It may be every three meters or every five meters or every 10 meters, "Here's the grass. Here's asphalt. Here's dirt. Here's rock. Whatever." Then we've got this library of textures that we ship with our product that says, "Okay, anyplace in the world that says it's rocky, we're going to put one of these three rock textures there." That happens automatically at runtime so that nobody has to go build these worlds with an artist scoping things out.” (GeoI_3)

The commitment to texturization and detail within the graphical output within modeling and simulation demonstrates a major change in the methodology of game developers and geospatial developers alike. A reliance on real world photogrammetry and satellite data has led to more than an e a singular environment artist or a team of environment artists within game development. The integration of these two arenas has led to an awareness of the established technical processes to bring in real world data. The addition of real-world data into game engines/development is not a necessity but rather, this was described by respondents in all groups as being able to benefit immensely from inclusion of real world terrain data. VGI_3 details the development of this methodology. An issue described by many of the gaming developers and academics alike interviewed for this study was the advancement of real-world terrain generation's impact on the role of environment artists in game creation. VGI_3, a distinguished engineer at Nvidia and a leader in graphics processing research, explains the impact of this trend:

"It's, you know, so what they're trying to do is really trying to simplify the artist's life by not having the artists have to painstakingly paint where all the little trees are and where all the dirt is and all that kind of stuff. But to try to give them sort of rough tools where they can kind of say, "Put some dirt here, put some paint, put some trees here,", try to get some rough thing, or even just say, "Oh, here's our terrain. Assume above this elevation that is going to erode, and it'll taper off into just dirt or stone," or whatever. And then just apply a lot of automatic methods that try to build up those textures in a hopefully tweakable way…artists are expensive." (VGI_3)

VGI_3, whose research in the graphics processing and rendering space has comprised much of his career, describes the impact of providing high-intensity graphics toolkits and incorporating terrain models based on real world DEM and satellite data has had on the game development space. No longer must game developers or those in the modeling and simulation space invest time, money, and effort to render and detail each and every aspect of a desired game environment. Instead, the inclusion of geospatial datasets and methodological processes, as described by respondents, reaped tremendous impact and benefit for those in the game development arena. Geospatial developers, whose work rely often on the inclusion of an environmental artist to create 3D environments can learn from the game development world as they attempt to grapple with individuals whose role would traditionally fall within the coded term "environmental artist" to appreciate how high quality geo-rectified geospatial data sources can be rendered with attention to aesthetic detail as well as geodetic correctness.

4.3. Human Computer Interaction (HCI) in Coded Reference

Much can be garnered by the geospatial community from the common technical and methodologies of game developers to enhance the user's experience. The nature of the game space intended by the creator is to provide an immersive experience that captures the user's attention (Roth 2017). A wide array of elements were examined and dissected through interviews with the SME interviews conducted for this study with reference to Human Computer Interaction (HCI). Section 4.3. focuses on the methodologies currently at play in the game development sphere and how they may be put into practice for the benefit of geospatial developers.

4.3.1. Navigation as a Term in Coded Reference

The methodological choices made by game developers to help aid a player/user helps present important considerations for geospatial interfaces together with the designers and creators behind them. A recurring concept regarding wayfinding occurred often in describing many of the conceptual lessons geospatial technologist can stand to garner from interaction the game development arena by SMEs in this study was that of markers of wayfinding points by which to guide the line of sight of the player or user of a gamified environment. VGI_ 3 describes techniques to help improve user navigation in a game platform through the use of wayfinding markers in the form of "lighthouses":

"…game designers [can] put up little lighthouses if [they] wanted to have a track where you are, if you're walking around... You're like, 'Okay, this is much better.' So, it's exciting to see that that technology's really, yeah, it's just getting better and better." (VGI_ 3)

VGI_3 uses the concept of "lighthouses" as an example of just one strategy employed by game developers and interface designers to help 'light' the pathway of a given player. Moreover, VGI_3 highlighted how advances in the strategic placing of wayfinding markers to be placed strategically so the user can improve the HCI of the user in that game space. VGI_3 was one of many respondents who emphasized a similar method in their workflow to help improve HCI within a gamified environment by examining the parallels between how wayfinding can benefit more standard digital mapping or within a more traditional GIS interface. VGI_1 made note of a similar method of specific eye-catching symbology placement spread along a given track or path for the user to follow through game-space:

"…there's all sorts of different ways to provide these types of visual breadcrumbs and glowing indicators to make it clear where you need to go. And so if you have a top down map, you'll generally show those on the map as well, along with little lines on how to navigate there. In the 3D space, it's trying to show you in real time the best ways to go. But then the even less obvious ways in terms of guiding the player is it's more of a curated artistic experience." (VGI_1)

The aesthetics of these markers within a gaming setting are of considerable importance when improving and adding to the experience of the player. Methods of guiding the player to their intended target through visual clues was a common thread in the SME interviews for this study. Attention to aesthetics and illustration in presenting object-based clues plays an integral role in providing a literal path for the direction of the player. The ability to move through a space is essential for the enjoyment and success of a game. These markers are made with tremendous forethought and cognizance of HCI by game developers. VGI_1 described a variety of examples in which this wayfinding methodology is applied. When successful, it can guide the user through the game environment and improve their experience as they interact with and move through the game interface:

"And so you might have a green field, but if you want the players to find the one little hidden object in it, you'll probably put some purple flowers or something that don't appear anywhere else in that field heading in a direction. And so it's the one piece of color that you see in an otherwise bland field. And so there's nothing hitting the user over the head saying, 'You have to go over here.' There's no arrows blinking, but people will just feel compelled to follow this chain of flowers, and they'll end up at whatever spot you wanted them most of the time. And so that level of curation and art direction to me is really at the heart of how you can control a player's navigation through a level." (VGI_1)

Eye-catching markers that guide the user described by respondents as an essential piece of providing a satisfying user experience. It ensures that the user ultimately meets the objectives of the game and reaches the final point within the game space they must reach to be successful. The importance of direction, a feature that is oftentimes a complicated aspect of HCI in the geospatial context, is mirrored within the game development arena. Importantly, the methodologies applied by game developers approaching this challenge were described in great detail by the SMEs across the industry and academic divide within game development. This was also discussed as a potentially helpful means for geospatial technologists to gain a great cognizance of the aesthetics needed to help improve a user's journey beyond the pure display of coordinate-based geospatial data.

Aesthetics in the game engine for creators, developers, and designers was described by respondents in this study as an imperative aspect of successful game development. Technical advancements and development have provided newer ways to provide inventive methods of wayfinding and navigation in serving to institute a system of directionality and position for the user in a given game space. Advancements in the gaming and technical arena described by respondents in this study which help to advance the progression of Augmented Reality (AR) and Virtual Reality (VR) also poses unique lessons for geospatial developers or designers of digital mapping interfaces. As VGI_1 expands upon:

"…another thing that the game developers have been dealing with for years is simple, intuitive means to interact with the data or the world, such as navigation or UI user experience, that kind of thing and especially, there's navigation in the traditional sense, how you describe to the game what you want your experience to be, how do you get from A to B. But there's also a new frontier with virtual reality. So far it seems that some people can handle VR…And so, I think there's quite a lot of history there in the games industry that anyone making an interactive map should probably research and draw on." (VGI_1)

HCI methodologies, which are essential to the process of creating a satisfying and goal-oriented experience for the player, are described by VGI_1 as presenting substantive lessons from which the geospatial community can learn from. As geospatial technologists push toward AR and VR depiction, navigation strategies and the corresponding methodologies addressed by gaming SMEs are of particular significance for traditionally oriented GISci technologists.

4.3.1.1. Coordinate Systems in Coded Reference

The usage of geospecific coordinate systems within the GISci community and corresponding body of knowledge cannot be overstated. To that end, coordinate systems represent the framework of GIS from a education-based perspective (Unwin et al. 1990; Oberle 2004). Coordinate systems play a key role in game development environments and game engines and thus is an important subject of note for geospatial developers. The 3D representation of data within a game engine has, based upon the literature, has allowed for engine or software-specific coordinate systems in light of the given system. The coordinate systems in a 3D platform consists of a nomenclature that differs from the GISci context. Game engines like Unity and Unreal Engine rely on x or y axis-based coordinate systems in manipulating and/or dictating the movement of game objects (Figure 8). Understanding the differences between the coordinate systems and geometry across the 3D modeling software used by game developers to create and design game interfaces.

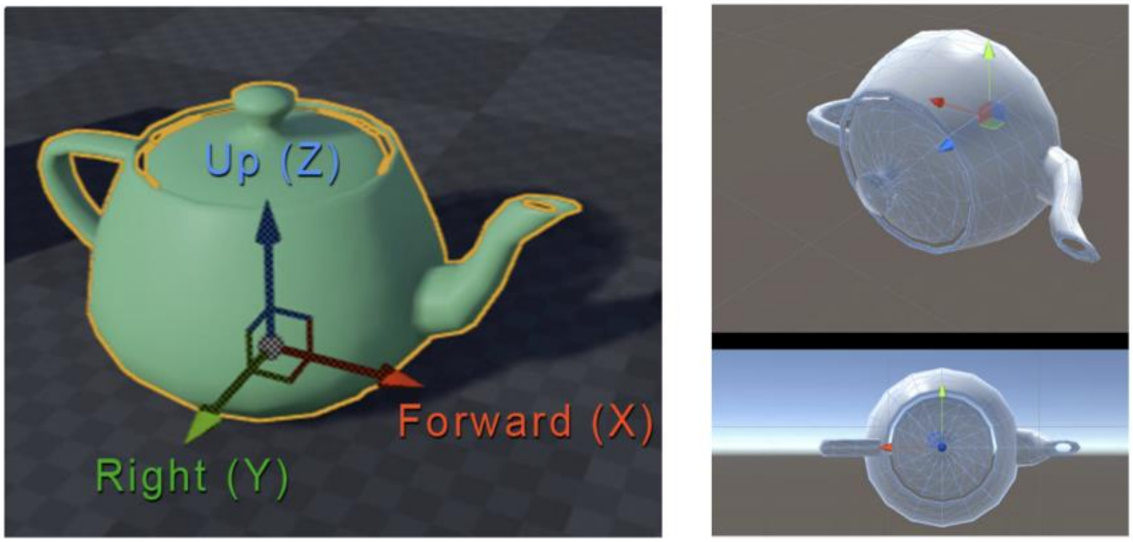

Figure 8. Vector coordinate systems in Unreal Engine and Unity

The methodological approach to coordinate systems plays an integral role in developing a game interface. GeoA_1, whose career has been spent in the modeling and simulation sphere, expresses the importance of coordinate systems and geometry plays in creating a geospecific environment on the part of the developer. GeoA_1 recounted how coordinate systems can impact the ability to call upon data within a game engine and manipulate elements within it:

"…a coordinate that could be pulled if you had the ability to script something, and say, okay, show me the coordinate inside game space, where [a] foot is hitting. You would get a coordinate, but it wouldn't be the real world coordinate. But the point I would make is that if you knew at that point in time inside the game space, what that piece of terrain was like at that point in time. So data that was collected as an example, after a two hour rainstorm on a football field that was outdoor and it was a grass field. Well, you're going to get a very different response when you put a 300 pound lineman on that piece of turf than you would on that piece of terrain that was in the perfect conditions of say Los Angeles, where the weather's perfect all the time and you never get these heavy rainfall." (GeoA_1)

A coordinate system plays a key role in depicting a real-world environment. GeoA_1 described this as having corresponding ramifications for modeling and simulation endeavors.

Understanding the nuances of coordinate representation and vector geometry provides insight into the methodological choices geospatial technologists can make in representational HCI choices. This has ramifications from both a functional exterior-facing perspective as well as a computational one, particularly in considering conversions between software systems.

4.3.2. Dimensionality as a Term in Coded Reference

A unique attribute of HCI that is specific to game interfaces is the multiplicity of dimensions in presenting a cartographic depiction of the game's location and setting. Access to multiple game map views plays in an important role in how HCI and navigation methods are provided through a video game interface. The ability to toggle between maps and encapsulations of 3D space advance the overall enjoyment and functionality of the player's experience as a whole.

VGI_1 describes a variety of dimensions present in the game in the game Deep Rock Galactic and how this capability within the game impacts user experience (UI):

"…there's a couple different ways to look at [dimensionality]. So the obvious version is just the concept of maps. And so this is anything from a mini map that appears in the corner of your screen, just showing a top down view of where you are in the world, so that you have some sort of spatial awareness while you're moving around in 3D space of where you are relative to other things at a further distance. But some of the less obvious ones are... The indicators that are in the game. So when you're on a quest or you're trying to drive to a target, how do you guide the user to that? And that can be as simple as a little compass arrow that's blinking in front of you. It can be a bunch of... There's a game that I'm playing now, Deep Rock Galactic, where to get back to where you need to go, a little robot walks a path in front of you, but leaves little flags, every meter or so, to let you know what path you need to follow. And so as long as you follow the little flags that it's stuck in the ground, you get to your destination." (VGI_1)

The dimensional viewports within the game interface is not unique to Deep Rock Galactic described by VGI_1. Mini-maps and other dimensions serve as a common visualization technique for a variety of game titles in order to provide insight and perspective by applying the diegetic immersion of the map interface into the viewport (Roth 2017). Nintendo's *The Legend of Zelda: Breath of the Wild* represents one such title in which vantage points provided through various dimensional mini-maps throughout the game experience are included.

Controlling the view of the player allows for important POIs (points of interest) to be highlighted throughout the game experience. The ability to hold certain aspects of the game landscape depending upon the game player's direction functions much in the way a digital map found on a mobile device might be seen within a real world context. Decisions as to whether to display particular views within the game can significantly impact player experience. GeoI_4 expressed how this phenomenon takes place within game space, explaining that:

"…[in] some geospatial applications too, but sort of mostly prominently maybe and most ubiquitously in games. The world that you're seeing within a 2D or other viewpoint is almost assembled dynamically on the fly based on the particular viewpoint that you have, much more so than it really is just dropping you into something that exists in a file format-y sort of way, like as you're viewing say a nature scene with mountains in the distance and trees in the foreground and all of that. More likely than not, the mountains are a drastically simplified view that needs to become more complex as you move closer to them, and the trees might be lower levels of detail, or just 2D sprites that are sort assembled for all of the reasons of optimization that you need to be able to do these things in real time." (GeoI_4)

Providing a view of a particular dimension of the game experience plays an important function in the HCI inherent to a given game. This also presents decisions to be made on the part of the game developer in terms of what should and should not be rendered in the game view to control the player's navigation experience. The decision on the part of the developer in choosing not to display a particular feature within the game's given landscape, as GeoI_4 mentioned, can help simplify and amplify the user experience (UX) in allowing a more direct view of what needs to be accomplished to advance within the game.

Mini-maps and multiple dimensions in the game space allows the avatar associated with the individual to feel more immersed within it (Cartwright et al. 2001; Thorn 2017). Closing the cognitive gap can be provided through mini-maps or active-maps which allow the player to split their attention to the game at hand while all the while keeping the game map top of mind, much in the way a real-world digital mapping interface might be referenced while moving through a locale.

Certain techniques allow the dimensionality of map viewports to partner in tandem with the waypoints across the game's landscape. This technique is known as the "golden path technique". The golden path technique is often described outside the world of gaming or geospatial development simply as the key steps a user is shown and then takes to find a product's value and optimize their experience. In the context of video game design, the golden path technique describes the path laid out for the user through a variety of dimensional angles combined with specifically placed POI waypoints throughout the game. VGI_2 recounts how this technique plays out within a game development and design context:

"Mini maps, other navigation tools just encompass waypoints, that kind of stuff. Might not be using the right term here, but there is a golden path technology where if you know where the user's supposed to go, you actually physically show them in the world where it is. There are all these visualizations, which are totally going to cross with the real world as AR devices become more prevalent, so then you'll be able to actually have navigation guides and things like that on a pair of glasses that you're wearing." (VGI_2)

Functioning much in the way digital maps include AR navigation arrows and/or devices, the use of multiple viewports for the screen view provided to the user combined with strategically placed waypoints aiding to optimize the travel time of the player within the game interface. This was s described by VGI_2 as. The golden path method provides a means by which the player can more easily move through the game, a technique that might potentially prove useful to geospatial developers and designers with similar aims.

4.3.3. Interactivity as a Term in Coded Reference

“Interactivity” as defined in this study as the way a user or player interacts with the digital environment in which a gaming or digital mapping takes place. The nature of “Interactivity” was mentioned frequently in both the literature review and throughout the SME interviews. Gamifying geographic and locational data can improve the level of interactivity experienced by the player. This can provide insights into the appropriate cartographic design choices interface designers and UX/UX engineers can make in providing digital maps. The ability to take in and grapple with geospatial data while providing a clear path forward for the player. Commonalities within the design of interactive user interface can be found in game-specific platforms as well as digital mapping formats. GeoI_6, who has published on the topic of “Interactivity” within cartographic interfaces in game environments, cited the Apple Maps platform as one example of interactivity UI/UX workflow drawn from gaming environments applied to real world digital mapping formats:

“Apple maps and their latest release of some very detailed three-dimensional buildings...they're also leaning on some of that same software that game developers also use, too. So I think technology is big. But more importantly to me is the user experience. In that both game designers and map makers are designing experiences. In my opinion, they should be. You're designing a map to be used in a context to solve a problem. Or maybe not. Maybe to just evoke something. It doesn't always have to be about work. But, it is about who is reading it in the end. And the same thing is with games. If you're not prioritizing that game experience and that user experience, your game might fall flat in terms of being received and being fun.” (GeoI_6)

GeoI_6 describes the responsibility of the map creator within a gaming or a digital mapping platform to create immersive and engaging interfaces for the user. The game experience, because it is typically an entertainment medium, necessitates the use attributes to create an interface that holds the attention of the player. The coded term “Career Connection to Thesis Subject” in GeoI_6’s case lined up with “Interactivity” as a code, it is no doubt unsurprising that results depicted from the NVivo interview content analysis (Figure 9) show a number of SME's mentioned "Interactivity".

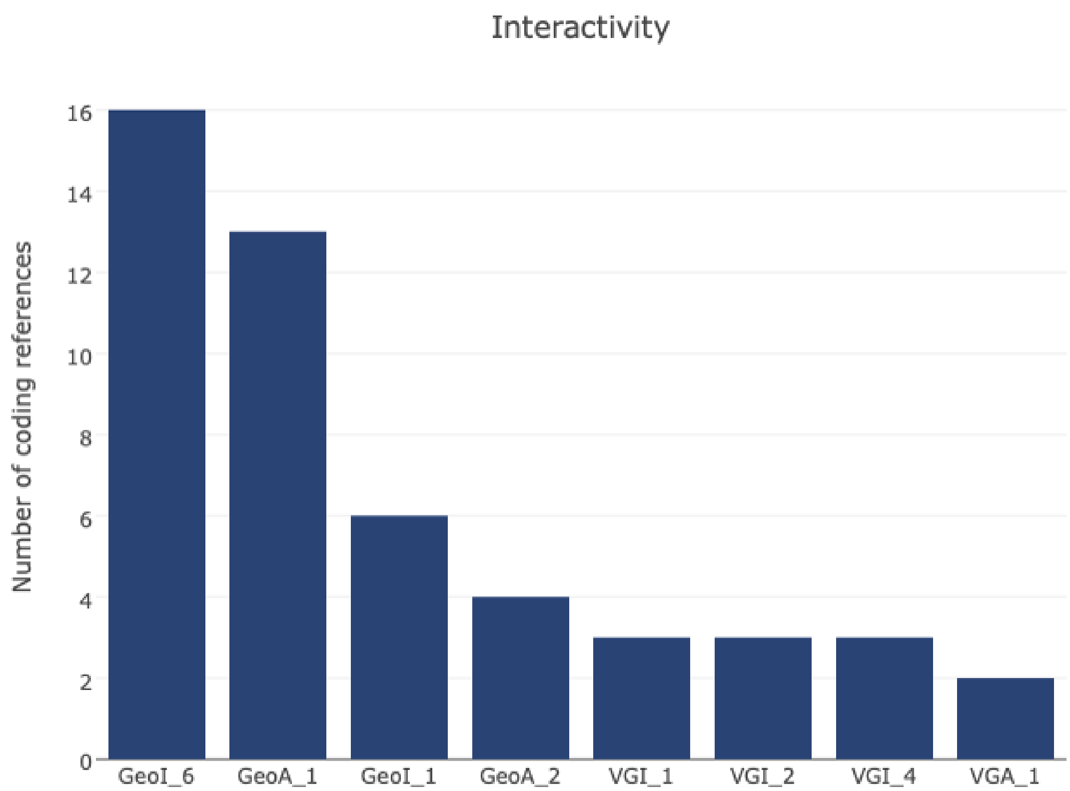

Figure 9. Number of coded references to "Interactivity" by SMEs

Enabling the user to successfully move from their location to a desired one was discussed by GeoI_6 as an element that requires a level of entertainment-based engagement to hold the users attention as they navigate to where they'd like to go using the map interface. Apple Maps, for example (seen in Figure 10) provides a detailed and engaging scene from which to view 3D data. Map makers and designers in the geospatial and gaming arena creating traditional and game-based map interfaces respectively can design cartographically to improve engagement to improve the usability and efficacy of the product.

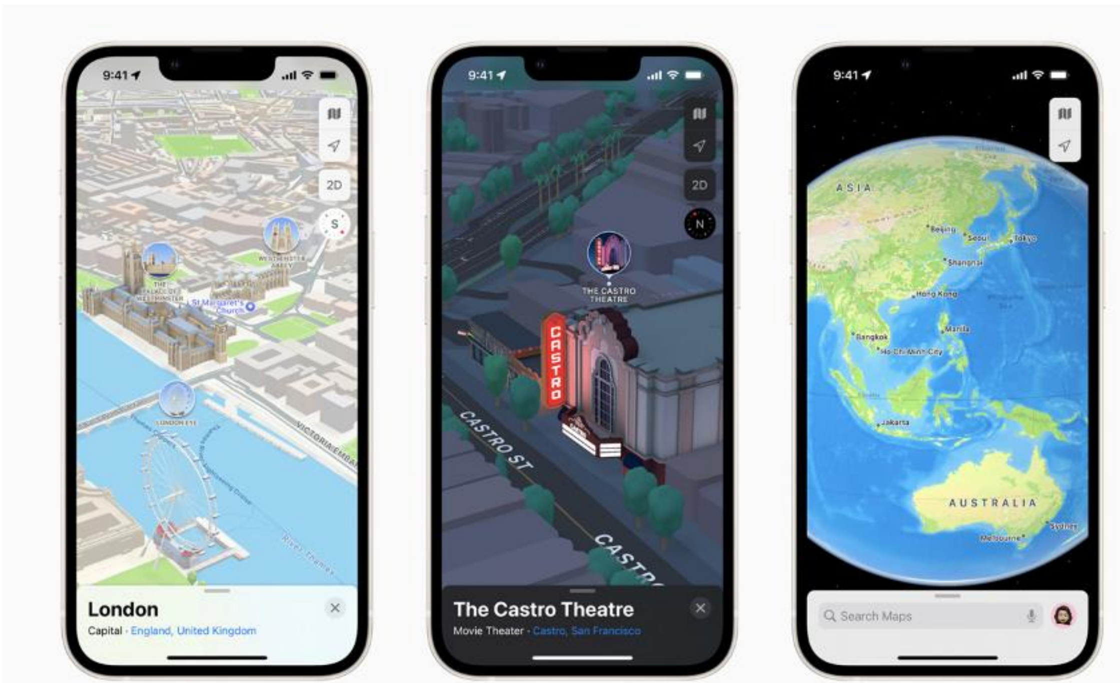

Figure 10. Apple Maps 2021 3D graphics release

GeoI_6 expounds upon a specific game-based example found in Firewatch (Campo Santo 2016) to explore how intrigue and fun can be used proactively to create an experience that inspires the player to move forward. GeoI_6 made reference to Campo Santo's Firewatch in light of the manner in which it:

"…[blends] between a classic user interface where you hit a start menu and then something else comes up like…. this is a completely separate space than the game [Firewatch]…if there's a danger in [Firewatch], there's limited danger. It's more of a walking simulator and you explore the story. But you don't always know that when you're playing throughout. It's like, is there something dangerous? Is there something that might trigger here? I think that they just did a standout job of a new mapping experience that I think a lot of other games could even learn from." (GeoI_6)

In Campo Santo, the game map allows the user/avatar within Firewatch to traverse the game map that holds the player's attention and facilitates a smoother pathway as they move through their objectives and provides an element of suspense, which was, recounted through by GeoI_6. In Ross Thorn's *How to Play with Maps,* he developed a code of "Interactivity". Thorn's definition of Interactivity, similarly, draws on the literature around HCI in game development and standard cartographic platforms by using variables which pertain not only to the player's ability to interact with the environment but also what he defines as *geocentric* as opposed to *egocentric mapping* (Thorn 2017). The difference between these terms is defined by the viewpoint of the game's interactivity as defined by the avatar's experience of the environment as opposed to the space in which the game is placed in looking in on the user but not centered on them (Thorn 2017). This speaks to an essential element of interactivity within gaming environments chronicled in the results of the interview questions with SMEs on the topic regarding the role of "Interactivity in more standard digital maps and game environments". GeoA_1, spoke to the way the rate of change of the simulation or game environment to adapt to the player creates an essential element of immersion and interaction in game space:

> …we're visual creatures. So certainly sight is the biggest one, which is why what we're seeing in these simulations is the most important feature that we think about when we interact with that game engine is how well does what we see inside the engine, does foreground, background, how do scenes change quick enough in order to keep up with how our sight would change? As an example, if we're driving our car 60 miles an hour down the road, how does that scene keep up to give us that same sense so that there's not a disconnect inside the game that says what there would be if we were actually doing it for real?" (GeoA_1)

The ability of a game or related simulation to change as a figure or avatar moves through it provides an essential element for the player in interacting with the elements inherent to a given video game. GeoA_1's described why the simulation of real-world scenarios or environmental physics as an important attribute in shaping the HCI of the player. GeoA_1 described temporal and immersive simulation, all of which play a role in helping define the nature of interactivity in game space. Frame rate, the rendering of scenes and the display of them as the player moves through the game, is a key tool in the game designer's attempt to create a navigable and interactive experience for the user.

4.4. Shared Challenges in Geospatial and Gaming

The ubiquitous code in the methodological processes described by game developers and geospatial developers alike was "Spatial Data". The definition of the coded term "Spatial Data" in the context of this study drew on the literature in both the gaming and geospatial academic and industry arenas. As such, reference to "Spatial Data" signifies data that contains information about a specific location on a geographic surface (Cartwright et al. 2001; Oberle 2004). While perhaps complicated, it is imperative to address the use of spatial data and databases in terms of how the two use cases within these spheres converge.

4.4.1. Spatial Data and its Challenges

"Spatial Data" and its use in collaboration with other technical communities is shown in Figure 11. The desire to harness the power of real-world geographic data has led gaming and simulation-oriented developers to use "Spatial Data" to ease the responsibilities experienced by an environment artist to carry out the rendering of a game's setting.

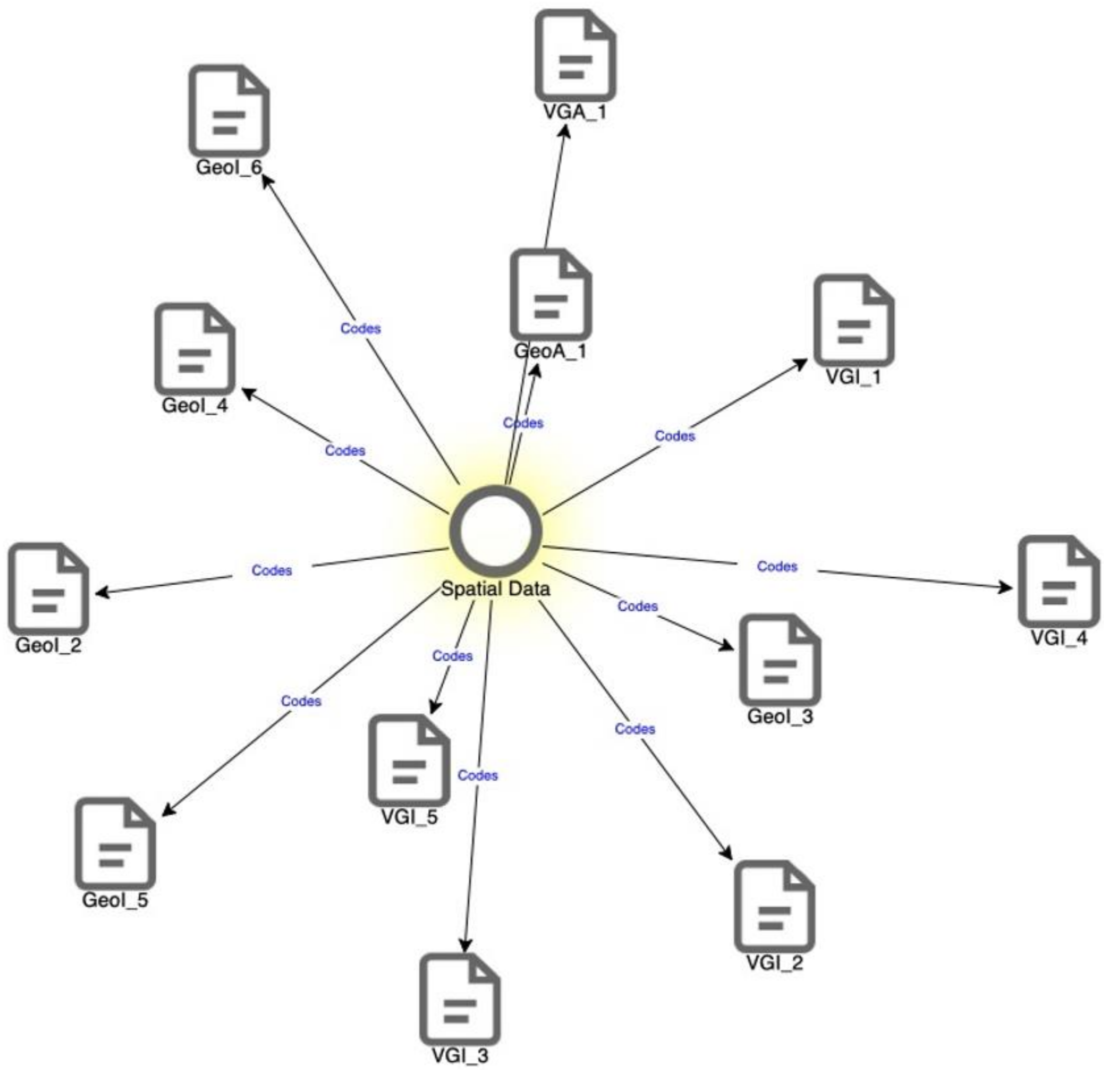

Figure 11. Spatial data key terminology web.

VGI_5 recounted the intersection of these two worlds as game developers turn to the geospatial community for insight as to how to bring "Spatial Data" into game development software platforms:

"Simulation has grown up saying, 'Hey, I want to simulate the world to some extent.' And as more and more data has become available, simulations have said, 'Well, why don't, instead of simulating in a made up place, instead of saying, here I'm just some random not realistic location, why don't I take that geospatial data and simulate where I'm actually going to go operate.' Whatever that operation happens to be. 'Hey, we're going to sort of cross paths with geospatial people and we're going to figure out how to take geospatial data and build it into our simulation, so that I can take shapefile, all the different data formats that exist from geospatial data. And I want to plug it into a simulation engine. And now, instead of just being on some random piece of earth, I'm actually looking at the mountain range or the set of buildings or the road, whatever it happens to be whatever the context happens to be.' They can look at it in real-time. And that's been hard to turn that data into realistic looking environments has always been hard." (VGI_5)

VGI_5 explained how connection between the geospatial and simulation fields combined with the motivation of gaming/simulation developers became focused on creating environments which could accurately reflect the real world. This drew on cross collaboration and methodological discourse between these communities as simulation developers began to focus on using spatial datasets to create game environments. Instead of opting for a method by which engineers needed to start from scratch to build games, game developers saw the benefit of drawing on input geospatial data from pre-existing environments to then input them into a gaming context (Gotlib 2016; Kiel et al. 2021).

The intersection of the two arenas was furthered by the desire to incorporate elevation data, while preserving clarity, within both contexts. The use of Digital Terrain Elevation Data (DTED) prompted technologists in both fields to utilize this elevation and contour data in novel ways while preserving data integrity. This occurred as the number of use cases in both more traditional DTED file format, as well as within a gaming context, began to grow in number and type (Vadlamani et al. 2004). Elevation data, paired with satellite earth imagery and LiDAR data, prompted greater ease of use and flexibility (Li et al. 2020; Zou et al. 2020). GeoI_3 discussed the use of Digital Elevation Model (DEM) data and other such aerial-borne spatial data as a key factor when inputting the data and 3D geometry into geospatial tiling systems. GeoI_3 recounts the transformative use of aerial-derived spatial datasets within 3D terrain tile grid systems:

"The evolution there…is that historically, people have always started with what we often refer to as source data, which historically has usually meant elevation data about the world, right?

They're usually distributed in DTED format or more recently sometimes in GeoTIFF or whatever. It's basically elevation data that's separate from imagery or anything else, right? It just tells you the height of the terrain, height of the world at every location at some grid post spacing. It could be there's a grid post every 1,000 meters or it could be every meter or whatever, depending on how high-fidelity your data is. That often, I think, used to get built from satellites or whatever, but now, it's more often this higher-fidelity aerial data, and it's either built using LiDAR or sometimes these days just photogrammetry, just generating the free data from images from taking images from multiple locations and then figuring out the 3D geometry from that. Either way, there's elevation data." (VGI_3)

VGI_3 described the manner in which multiple sources of DEM data provided a new method of orienting elevation data along a cartesian grid. Advances in aerospace over the past two decades has further accelerated the zoom level. This is when satellite and elevation imagery is captured, resulting in use by both the geospatial and gaming arenas (Zou et al. 2020). Spatial data in elevation-oriented formats provided a new source for 3D geometrical manipulation and creation.

More traditional forms of spatial data utilized within a standard GIS workflow has been of use within simulation and gaming contexts as the gaming and simulation community desired to provide geographically-accurate representations of space (Evans 2002; Neteler 2004). VGI_3 brought up the use of OpenStreetMap data sources in building a game environment while discussing spatial data types that GISci technologists might be more familiar within from their standard methodological workflow:

"The OpenStreetMap data tells us there's point features…There's point features for each of the power line towers, right? And there's an attribute that tells us it's a power line tower. Then our [simulation] software can go in and say, "Okay, since we know they're power line towers, we're going to create polygons to string the actual power lines between the stations." That's not part of OpenStreetMap. That's not part of the source data directly, but that's kind of our logic that's interpreting those things as power line towers so we know we should align them with the linear feature because I guess their power line towers are usually, I think, described as linear features, which is helpful because then you know where to run the lines." (VGI_3)

Attribute data that might traditionally be visualized by GIS practitioners to generate 2D representations of geographic space is manipulated within a simulation to display what might otherwise be represented as linear non-geometric features. OpenStreetMap data, the predominant open source data used to orient the basemap within traditional GIS contexts (such as in the case of Esri's ArcGIS) might be of constant use by GISci practitioners. However it can also be adapted to generate a more diegetic sense of space for the user of a game or simulation experience. Innovation within the 3D data processing space has further promulgated use of more traditional spatial data formats for the purpose of simulation within the gaming arena (Hadimioglu 2019; Tauscher et al. 2021).

4.4.1.1 Coded Reference to Specific Spatial Data Types

Specific data types within a given domain become a part of the common vocabulary and were discussed by developers and technologists with relation to their impact on the field. A reference to "Specific Spatial Data Type" was made mention of by SMEs with respect to the application of these file formats and the issues relevant to that file type in common practice. SMEs discussed a wide variety of file formats, specifically spatial data, in terms of the technical workflow present in each domain in working with specific file types (Figure 11).

The professional practice of when creating standard GIS workflows makes use of a bevy of spatial data sources. The most used vector file format in use by GIS technologists is ArcGIS Esri's Shapefile (.shp) format. Shapefiles, when used within a GISci context, t provide attribute and informational data. GIS software's output typically displays this informational inside a 2D representation of space. Beyond the basic GIS use cases, processing advances have provided a method by which one can manipulate and display geometric shapefile data types (Herrlich 2007). 3D depictions of traditional feature data through algorithmic manipulation of this file format presents novel use cases for otherwise 2D vector datasets. VGI_3 described the process behind applying and making use of shapefile formats specifically within simulation software:

"The point is the runtime software can make some decisions that used to happen in these offline tools when they generated the visual database. Now, you can essentially generate the visual database at runtime on the fly. There's all kinds of decisions the runtime engines can make to do that for how they process that source geospatial data…By the way, the source feature data often comes out of tools like Esri's ArcGIS or QGIS or things like that. That source data is often saved out in formats like shapefiles, and then software like ours can read shapefiles. It can read OpenStreetMap databases and other formats that save that sort of feature data. Then we combine that with some logic and configuration that we have in our software to be able to say [that] whenever a building [is] residential and the stories parameter [is] 'Three stories,'...a hand-model building or I've got a library of hand-model buildings that I'm going to randomly select between and place them into the scene.' You could either just literally take the footprint and just extrude that up into... so you've got polygons for walls that's the exact shape of the building or you can say, 'Okay. Well, I know that building's a three-story building. I know it's residential, so I'm going to go to my library of 100 buildings my artists have built, and I'm going to randomize between them.'" (VGI_3)

Object identification software and algorithmic translation of 2D feature data into 3D projections is made possible through the application of this commonly used GIS file type. The shapefile, while otherwise used as a more static 2D result of a GIS process, is made use of within a gaming and simulation context to arrive at a 3D result. As explained by VGI_3, computational graphics processing methods are applied to the shapefile format to develop multidimensional ways of viewing this type of space. The modification through algorithmic manipulation of otherwise 2D shapefile content to 3D file formats has also been witnessable through recent advancements in the geospatial community, such as ArcGIS CityEngine software. The move toward 3D display of geospatial data can also, in part, be credited to the desire of those within the simulation arena to display shapefile data types and otherwise standard spatial datasets to create geospecific content (Herrlich et al. 2010).

Beyond the more commonly used spatial data file types such as .shp or DEM, photogrammetry data, which has seen a rise in use by GIS practitioners inside their standard workflow has similarly been borrowed from geospatial technologists by the gaming and simulation communities (Nogueras-Iso 2004). Photogrammetry data is used by GIS practitioners to create geometric meshes and thus display the geometry of a spatial object (Optiz et al. 2012). Photogrammetric data has also been used within game engines to aid the workflows of technical art teams inside of game development cohorts.

The use of photogrammetry data to improve the creation of game settings is described by GeoI_4 with respect to how it can be used outside of the geosciences:

"…material scanning and material libraries that start to collect what the physical properties of these things are that make workflows better for the [game development] artists. I know photogrammetry collection and stuff has been really interesting to see starting to become a commodity thing that you can do with a phone these past few years too…in terms of making it easy for individuals who want to build something…that lowers the barriers a lot I think." (GeoI_4)

VGI_3 explains that teams of artists using photogrammetric 3D scanning to manipulate a set of images can be used as a method to supplement gaming workflows beyond the geospatial context and render objects in 3D space. Similar sentiments were echoed in respondents' answers with reference to "Specific Spatial Data Types" (a coded sub-header underneath the larger banner of "Spatial Data"), as a source used in NASA's Mars 2027 simulation. Photogrammetry data can be used in the gaming community for manipulating the geospatial context (such as in MeshLab or Autodesk ReCap) to visualize place-based geographic information (Horn et al. 2017). VGI_2 went into significant detail expounding on the use of "Spatial Data" as a coded term and, more specifically, the use of photogrammetric methods and photogrammetry methods and its popularity within a game development context.

Non-traditional 3D spatial data types have increased in popularity by the GIS community with the release of tools such as Esri's ArcGIS CityEngine (Arnold et al. 2018). 3D file formats, the predominant file format used within game development artist workflowsh, are nothing new to game developers. As GIS practitioners more regularly apply 3D data to software like Esri's CityEngine, much can be gained through the use of file formats common to the game development community (Silva et al. 2018). In examining the responses of game development and computer graphics-oriented respondents, a clear thematic parallel was the development and use of file formats such as COLLADA or USD to help set the standard for 3D content. VGI_4 chronicled the historical development and rise in use of these common 3D formats:

"…I think it was Sony tried to create COLLADA which was going to become a common 3D model format. More recently Pixar and others have pushed for either USD, Universal Scene Descriptor, or GLTF. And so there's... But each one of these attempts at making a common format has made another common format for people to support. And so we do have…fracturing of common formats." (VGI_4)

USD and COLLADA data, as explained by VGI_4, rose in popularity as a universal system from which to draw on 3D data and create 3D content in game engines and simulation software. The use, application, and potential pitfalls of these data types remains an important element of consideration for GIS technologists who are making more frequent use of 3D file formats. As GIS technologists develop their workflows and depictions of 3D geospatial space, graphics principles used commonly by game developers will be necessary to keep in mind. As USD and other 3D data are applied with greater frequency across a variety of contexts across gaming, simulation and beyond, GIS practitioners have much to garner from understanding the use of these file types in different settings to appreciate their use in the geospatial arena. VGA_1 explained that:

"…with USDs and omniverse, [3D digital creation] is becoming more, it's getting easier. It's still hard, but it's getting easier. And then the other part of it is if we imagine that visual computing is booming across these industries, and particularly because of real-time graphics…involved in creating virtual worlds." (VGA_1)

USD and other such file formats rely on 3D objects and 3D data manipulation in their workflows. These were highlighted by VGA_1 as a way for geospatial technologists and related fields like BIM (Building Information Modeling) to utilize the 3D file formats to gain traction in GIS. The coded phrase “Specific Spatial Data Type” is worthy of dissection in better appreciating the exact points of intersection and context from which the gaming and GISci communities cross paths.

4.4.2. Challenges in Working with Differential Spatial Data Types

Learning from the shared challenges between the GISci and gaming/simulation communities speaks to the fundamental motivation for this analysis. The application of “Spatial Data” and “Specific Spatial Data Types” as came with a variety complications and challenges reported by SMEs (Figures 12 and 13). Many of these issues spanned sectors as technologists within both domains expressed similar pain points within their technical workflows. In appreciating these challenges, it is also worthy to make note of the troubleshooting methods implemented by SMEs in both these fields to tackle these issues.

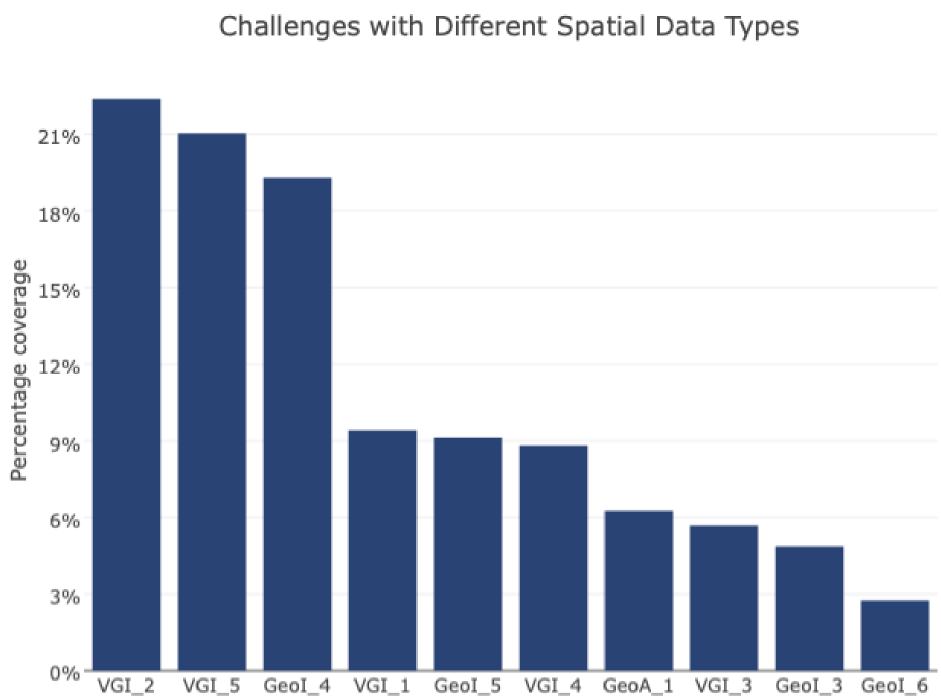

Figure 12. Percent coverage of code "Challenges Working with Different Spatial Data Types".

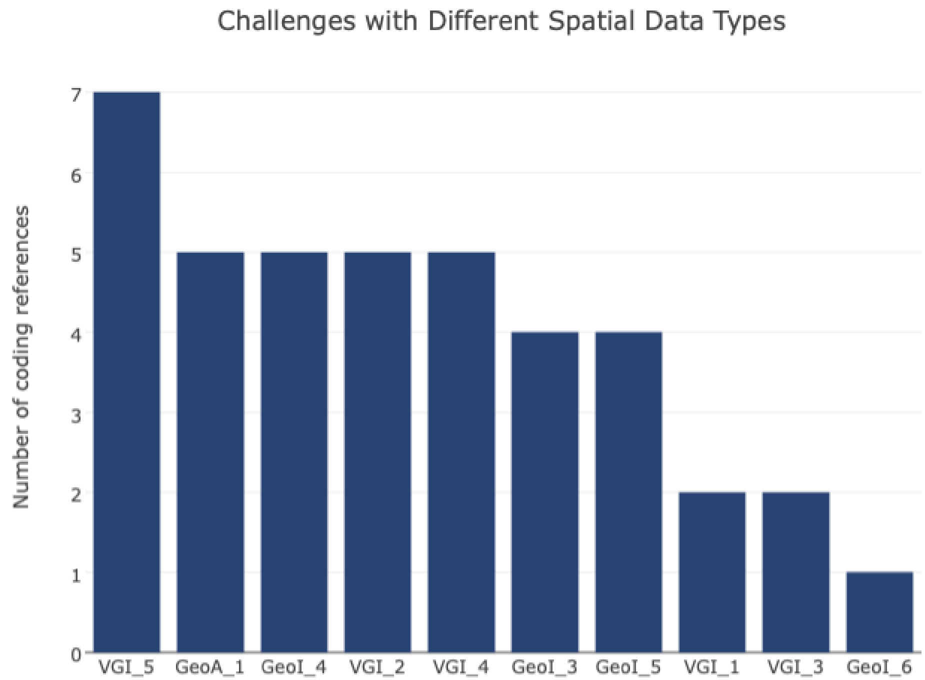

Figure 13. Number of coded references to challenges working with different spatial data types.

An issue commonly cited by GIS practitioners and game developers was combining and interacting with multiple types of spatial data derived from a host of origins and file formats. As data sources in geospatial and game development creation have diversified in finding new inputs and data capture methods over time, the complexity of combining these files has become particularly arduous (Nogueras-Iso 2004). Moreover, the orientation of these spatial data sets in different projections and coordinate systems provides yet another layer of complication in working together with these data types. VGI_ 1 explains this issue within a game development context:

"…there started to become just some format issues because different types of [3D software] had different types of formats…And so we've got [that issue], and that's just for even describing what data is and how to get it in. But then the past three to five years, this is where I think it probably intersects more with what [GIS technologists] are used to, which is now that we're starting to take in things like satellite data and LiDAR data and point clouds, that's far more complex because none of that data is in a form that's immediately useful to a game." (VGI_ 1)

As VGI_1 explained, the inclusion of novel spatial data file formats has caused a myriad of issues for game development teams looking to make use of this real-world data to depict or simulate an environment. Particularly for those within the simulation community, this pitfall is a major methodological challenge within the gaming arena and developer community. Quite notably, geospatial SMEs respondents echoed almost parallel challenges in their technical workflow. GeoA_1's response to the prompt regarding challenges experienced in working with different types of spatial data types mirrored that of respondent VGI_1 almost directly, despite their professional orientation coming from different fields. GeoA_1 gave their thoughts on the challenges associated with the blending spatial data file formats:

"I think one of the big challenges is to make sure that the formats of the data that are used inside of that GIST environment that you're talking about, the format of the data, may not be the exact same format. In some cases, quite different [formats]...So getting those formats to be, I don't know that the word is interchangeable, because I don't think that's the word we're looking for, but certainly to be able to be used inside of both systems well, so operationalized maybe to be able to operationalize the data for real world application in that GIST community and to take that same data and then be able to ingest it..." (GeoA_1)

Errors related to working with different spatial datasets are important. GeoA_1 expressed how this problem can stand in the way of operationalizing these data sources to portray geographic space. The complicated nature of preserving spatial data integrity within a GISci context while combining datasets of various types and sources was repeated at length by technologists interviewed for this study. Many also described the added complication of advancements in graphics processing to handle 3D data, which has an impact on the rendering of multidimensional depictions of geographic settings.

The complicated nature of combining and working with 3D spatial data files can be attributed to a variety of aspects. For one, the orientation of specific kinds of 3D data derived from different coordinate systems depending upon the 3D digital creation method used to create a 3D geometric object or mesh remains a prominent reoccurring issue. Much the same as described with 2D spatial data formats, the diversity of popularized 3D spatial data types that have become common practice has also created several issues. VGI_1 expands on this issue in practice explaining:

"…[3D data] comes in a lot of different formats and a lot of different coordinate systems, and so it's a lot of things that most game developers really haven't had to worry about or experience until recently and then even, yeah, the other kind of intersection is using CAD data…real world CAD models of cars, machines, things like that. As we try to start to bring some of that data into the gaming space, again, it's just... I think I had heard there were over 50 different common CAD formats. And so it's an explosion of data types, all just fundamentally trying to describe the same things, which is, 'Yep. Here is the surface of an object. Here's the geometry of it. Here's what types of things are on that surface.' But it's very... Yeah, there's a lot of different ways to do that." (VGI_1)

VGI_1 stated that the differential coordinate geometry associated with spatial 3D data can create trials and tribulations for technologists working with 3D geospatial data. The widespread popularity and application of using 3D visualization of data in both fields will mean issues surrounding 3D data and other unwieldy forms of spatial data may continue. .

However, as described by respondents in this study, remedying the problems surrounding spatial data handling and integration have been addressed in part through the development of a common file format. This was described by VGI_1 in terms of the frustration many developers across the digital asset creation and game development community experience in working with 3D digital manipulation software:

"…how you represent a 3D model might be different from Maya versus 3D Max versus ZBrush versus whatever art tool of your choice…there was definitely data format issues caused by that, but then what we started to see... And this has happened a lot of times over the past 20 years, which is a lot of people trying to start to create common file format types." (VGI_1)

VGI_1 explained these issues related to 3D as a result of the data's point of origination in addition to the coordinate system assigned to data created in that software lead. This led to the development of common file formats which enabled ease of use. Creating one industry standard across the board for this type of data was an important development within the gaming community. This should be noted by geospatial developers in dealing with the similar issues, such as when data clashes within a given software system.VGI_4 described an additional solution, namely how tools have been combined with common file types for ease of use in dealing with non-heterogeneous spatial data types:

“..in any one of these industries, usually any real workflow doing meaningful stuff, involves many tools within that same pipeline. Dozens quite often are used there. And, what's missing in the 3D world is a common standard for exchanging this data between them. We settled on one that Pixar introduced in Open Source back in 2015, called USD, Universal Scene Description. We looked at that and I looked at and thought, "Wow, this is the first time in the 20, 30 years I've been doing computer graphics that there's something that could possibly be this Lingua Franca for us…describing things in 3D is so hard…there's so many aspects to it that nobody could really agree on it before. I looked at it and said, "This feels to me like HTML in 1993." When I first saw it was released. The promise is there. It's extremely powerful and it's going to unlock all this other stuff, but it's not complete yet. There's a lot more we can do with it.” (VGI_4)

In recounting the history of the development of USD file types, VGI_4 underscored the potential common file formats can have in accelerating 3D digital creation and content. Common file format represent the opportunity for possibility, exchange, and technical advancement for both the GISci and game development community.

4.5. Parallel Recurring Concepts of Note

4.5.1. Specific Video Game or Gaming Company in Coded Reference

As conversations conducted with SME interviews progressed, certain games were mentioned that typified key concepts. These are likely the game maps that were particularly of note or exemplified the principles of the research and/or technical principles they described. A complete list of the video games mentioned by interviewees can be found in Table 7. Of the games that were mentioned in terms of the intersection between the GIST and the game development one, Horizon Zero Dawn (Guerilla Games 2017) and Halo Reach (Bungie Games 2010) were most commonly associated with the coded term “Interactivity” and “Navigation”. This was due to their immersive nature made possible through the use of avatars in both games. GeoI_6 made reference to the explicit steps taken by developers creating the user experience behind Halo Reach.

Video Games Mentioned by SMEs
Assassin’s Creed, Odyssey
Crossy Road
Firewatch
Bioshock (I and II)
Halo Reach
Microsoft Flight Simulator
Pokemon Go
Outer Worlds
Space Invaders
Zelda: Breath of the Wild
Apex Legends
Deep Rock Galactic
Grand Theft Auto (Vice City)
Horizon Zero Dawn
Mars 2030
Pacman
Quake
Skyrim

Video Games Mentioned by SMEs
World of Warcraft
Call of Duty
Elder Scrolls III: Morrowind
Ghost Recon Wildlands
Grand Theft Auto (San Andreas)
Legend of Zelda
Minecraft
Red Dead Redemption 2
Spiderman, NY
Tiger Woods Golf

Table 7. Specific Video Games covered by SME Interviews in this study

The two game-series brought up with the highest frequency were game maps based on real-world locations. Grand Theft Auto (Rockstar) and Assassin's Creed (Ubisoft 2016) series both were created using real world environments. In reference to Rockstar's Grand Theft Auto (GTA) and Ubisoft's Assassin's Creed, respondents discussed the use of spatial data in creating real world cities. GeoI_1 argued that Assassin's Creed: Odyssey (2018) typified ideal methods of real-world data acquisition and use. Geo_I discussed the attributes modeled by developers and game art teams in creating a realistic rendering of Greek settlements during the era in which the game is meant to take place (approximately 431 B.C.):

> "…one that really jumps out to me, and it's a series at this point…has been producing a series called Assassins Creed, which maybe you're familiar with. It's very popular. But most recently, my experience with one of their titles called Odyssey, Assassins Creed Odyssey. This takes place during the Peloponnesian War, and it sweeps almost the entirety of the Grecian sort of empire such as it was at the time. It was by no means unified, as many of us know. There were sort of generally the Athenians and then the Spartans, and then everyone

> else who kind of sided on one or the other, which is relatively close to how it happened as well…this is just a map of Greece. There's a couple of things shrunk or whatever, but effectively, I know the island of Catalonia. It's a real place." (VGI_1)

VGI_1 referenced a variety of simulated locations within the island of Greece and Catalonia which the Assassin's Creed Odyssey game map quite accurately reflects. VGI_1's observations regarding the creation process is supported by the literature of the cartographic development processes leading to the game map. Archaeologists and historical GIS experts were brought in to the project to ensure the authenticity of the game's setting (Politopoulos et al. 2019). Other coded references within the code "Specific Video Game Mention" described games based upon examples which were meant to reflect real world settings. Rockstar's GTA V map was brought up multiple times with respect to the layout and spread of Los Angeles (named within the game's context as "Los Santos"). To that end GTA: Vice City was referred to by interview respondents regarding its relationship to the city of Miami.

Another trend across interviewee discussions was the advent and rise of AR and VR methods within the coded term "Specific Video Game Referenced". Pokémon Go (Niantic 2016), for example, was described by many of the SME respondents with respect to the role the game has played in the application and wider use of mixed-reality platforms. VGA_2 pointed to Pokémon Go as an essential AR use case within the gaming space the role role has played within the larger game development and player community: "…you take a game like Pokémon Go, right, which is augmented technology, which is really interesting. And that alters people's perception of their local environment in a really kind of profound way."

To that end, VGA_2's discussion of Pokémon Go mirrored similar discussions as to the role played by specific games within a VR context. VGI_2's discussed theMars 2030 (Fusion Media Group 2017), a VR extraterrestrial immersive game/simulation experience. VGI_2 also described the impact of mixed-reality methods like that of VR on the game development world: "…there's also a new frontier with virtual reality. So far it seems that some people can handle VR. Other people make some kind of motion sick and people are still in the process and have been developing techniques to mitigate."

Potential drawbacks for VR games were similar to many of SME respondents' descriptions of VR within the coded phrase "Specific Video Game Mention". While many respondents expressed enthusiasm at this new medium, others also seemed hesitant to fully embrace the adoption of this medium in certain cases.

4.5.2. Specific Geospatial or Gaming Company in Coded Reference

With respect to the major trends, standout industry leaders described pivotal aspects within their workflow at the intersection of methodological approaches used by the geospatial and gaming sphere from an industry and commercial perspective. Companies in either space worthy of note (Table 8 and 9) were described by interviewees in part because of their relevance to these SMEs' respective professional journeys as well as these companies' relevance and contribution to the study's subject matter. These industry leaders are worth discussing in light of their connection to either the GISci or gaming in connection with one another. Oftentimes respondents mentioned these companies specifically to describe a corporate leader driving the intersection between the two fields.

Geospatial Companies Mentioned by SMEs
Cesium
Maxar

MAK Technologies
Bing Maps
Infinite Reality
Autodesk
Esri
MAME
Fusion Media Group
OpenStreetMap
Keyhole
Intrinsic Graphics
Nvidia
Blackshark.ai
Lumberyard
Microsoft
Google Maps/Earth
Silicon Graphics
Hewlett Packard
Pelican Mapping

Table 8. Specific Geospatial Companies Covered by SME Interviews in this study

Gaming Companies Mentioned by SMEs
Epic Games
Insomniac
Campo Santo

Ubisoft
Rockstar
Electronic Arts
Disbelief

Table 9. Specific Gaming Companies Covered by SME Interviews in this study

Given the degree to which GIS practitioners make use of Esri's ArcGIS software, it makes sense that Esri was often used in discussions of traditional GIS frameworks. Cesium also was described in depth as rapidly evolving the digital transformation and technical exchange between the two arenas mediums. In addition, Microsoft, through the use of terrain generation methods, was also described within this coded reference.

Industry leaders of note were also described by SMEs as coming from the game development arena. Ubisoft and EA Games were often described within the context of titles released by these companies which attempted to reflect real world environments in the creation of a game's environmental attributes. Most prominently among the gaming companies mentioned, Epic Games was mentioned as a means of describing specific game titles that benefited or stood to benefit from cross-collaboration with the GISci community. This was in reference to Epic's proprietary game engine software, Unreal Engine.

4.5.3. Game Engine in Coded Reference

The two major gaming engines described by the SMEs were also the most widely used game engines used by game developers and their teams. This includes both the high-end game development studios and smaller indie game studio production companies (Ciekanowska 2021). As discerned through conversations with geospatial and gaming-based interviewees alike, the application of game engines has expanded well beyond the gaming arena given the graphical capacity and output of game engine software in manipulating and working with large spatial datasets at high processing speeds.

4.5.3.1. Unreal Engine as a Term in Coded Reference

As described in connection to other coded terms such as “Spatial Data" and “Geotypical vs. Geospecific Data”, the development of Unreal Engine has accelerated the ability of technologists across domains to work with large datasets in central locations. Moreover, Unreal, Epic Game’s proprietary game development software, can take on data types of all kinds and render it with high-fidelity and without losing the integrity of the data. This was described by VGI_3, who explained how the work Epic has done by creating Unreal Engine provided the ability to turn mesh geometry into complex geometry. Part of the issue inherent to this process is the massive amount of data the game engine must be able to take in and process:

“…trying to take sort of high-risk scans and so on, turn them into these meshes that they can deal with at different levels of detail, kind of, you know, as best as they can automatically, but also, it's just a huge amount of data that they're dealing with. And they're doing a really nice job of like trying to solve that problem, basically.” (VGI_3)

In allowing the ability to take in 3D mesh data and other complex geometric data formats, Unreal presents a sophisticated software platform to render spatial data in high detail, as VGI_3 explained. Unreal provides the industry standard among game engines in its ability to take in data sets with complex geometry as well as dense datasets as a whole. This sentiment was echoed by academics in the game development space. The real-time rendering of data to create high quality performative systems provided a path forward for Unreal Engine to emerge as a leader in terms of rendering at high frame rates. This was echoed by VGA_1:

"…using Unreal as an example, you can bring motion capture in, you can do real-time performance, you can key frame and bring that in, you can layer it all together. So looking at different ways of authoring, not only the performance, but also the underlying motion system to make it perform…now that the visual fidelity of something like the Unreal Engine is getting up there where it's almost indistinguishable [with real life]." (VGA_1)

The output provided through the technical complexity of sophisticated game engine software like that of Unreal results in 3D graphical output so detailed it appears almost a mirrored twin to the real-life object environment. The sophistication of software like Unreal Engine will help push the bounds of what is possible both from a data input and graphics rendering perspective across industries and use cases particularly given recent collaborations of major geospatial 3D data company, Cesium to create a bespoke SDK.

4.5.3.2. Unity as a Term in Coded Reference

Unity's proprietary game engine software is the most popular game engine on the market today. The use of unity within the 3D geospatial content has been increasingly used, particularly in light of the recent Unity and Mapbox SDK. This helped develop and output high quality geographically accurate data within a game engine context. Advances in terrain generation and procedural modeling within Unity has provided a new conduit by which to go about processes for procedural modeling and real-world terrain generation operations (Jesus et al. 2012; Evangelidis et al. 2018). VGI_4 suggested that this capability within Unity and Unreal Engine will have major implications in terms of expanding high-level computing ability across more than just the gaming space:

"Today, the world simulators we have are primarily designed for entertainment. They're for video games. And they're awesome. Like Unreal Engine and Unity and all of the bespoke engines, every game developer, AAA game developers create, they're amazing. And they're beautiful. But, they're particularly amazing because they do all of this magic in a very constrained computing environment. They run on consoles that are 400, $500 computers, or they can run on your phone that's running off of a battery. So, they're really tuned and optimized to run on a minimal hardware configuration.” (VGI_4)

The comprehensive high-level computing power provided by game engines will allow for the expansion of these capabilities to technologists across different domains to gain access to graphics processing power. The ability conferred through game engines to process and compute rich datasets on a massive scale poses tremendous benefit to the geospatial arena along with other sectors in need of sophisticated computer graphics and software moving forward.

4.5.4. Graphics Processing in Coded Reference

Developers within the gaming and geospatial domains are increasingly finding touchpoints for technical and methodological exchange. At the same time, the field of computer graphics, a sub-field of computer science, is more generally concerned with the display of image content through pixel-based generation on a graphical interface. The field of computer graphics and processing grew up hand in hand with game development in that high-quality computational synthesis of picture data was critical for providing visually interesting and immersive content for a video game user. As computing power and processing improves over time, as Moore’s Law holds, computer graphics becomes relevant in non-gaming sectors such as the geospatial domain in which high-quality visual outputs of data (Schaller 1997).

The graphical output of spatial data is an issue that is currently one of many challenges facing geospatial developers. These developers must process data-rich graphics. This becomes important when creating geographically accurate and visually striking portrayals of the world. In light of the desire on the part of the GIST community to graphically output spatial data with graphical accuracy, corollary lessons in graphics processing have been sought out and borrowed from. Gaming platforms offer a parallel implementation of graphics processing methods to create large scale worlds and instances in creating Massive Multiplayer Online (MMO) or open world games, in which imagery-rich data must be rendered at runtime for the user. VGI_3 explained this phenomena within the context of graphics engineers tasked with instantiating open world games:

"Trying to figure out that problem of what do I do for the player, and, you know, there's sort of, within games development, there's a lot of interest in sort of open world kinds of things are just huge worlds, you know, World of Warcraft or whatever, or Grand Theft Auto V, or all those kinds of games where there's sort of these big, big worlds where people are wandering around. And how do you deal with that level of detail problem, really?" (VGI_3)

VGI_3 described the need for high-level computer graphics methods to provide high quality material output for the user. The computer graphics and processing methods implemented to output graphics-heavy content by game developers can just as easily be utilized by those within the GIST domain in service of detailed geospatial visualizations.

4.5.4.1. Rendering and Texturing in Coded Reference

Geospatial visualization technologists aim to render high quality and increasingly complex (such as 3D file formats) data types in their work, much like those in the gaming arena. Borrowing information with the game development community has been of significant value for geospatial developers. As GeoI_3 put it:

"Historically, people started with those pieces of source data and brought them into some offline tool. There was some specialized ones that people used in the modeling and sim industry where artists would take those things, and do a bunch of work, and then export a polygonal database. Convert that into a bunch of polygons with textures on them that could be loaded into rendering engines or as we call them in this space image generators usually. So you could bring that in, but it was kind of this offline process, and maybe you had to do some background processing and compiling, and then the tool 12 hours later would spit out this optimized terrain database that you could load into your system. That's how it worked for a long time." (GeoI_3)

As technology supporting graphics processing has increased in sophistication, users are no longer forced to endure long wait times in order to take-in detailed visual content within a software system or output onto a Graphical User Interface (GUI). This was discussed by GeoI_3. GPU computing ability and processing power has driven the adoption and use of ever-more complex geometries processed at increasingly faster speeds. Such advancements are relevant for consideration for geospatial technologists who stand to benefit in their own work from many of the graphics processing “hacks” (as described by GeoI_5) in practical use by computer graphics engineers and game developers.

High quality “Rendering” and “Texturing” abilities as coded terms within the overarching header of “Graphics” were used within the qualitative analysis conducted for this study. Graphics processing languages and tools such as WebGL or the advent of shaders to display outputs made possible via the use of WebGL within the graphics community. It has also provided a vehicle for hyper-realistic content driven by the computer graphics community (Evangelidis et al. 2018). “Rendering” was defined in this study as the process of generating a photorealistic or non-photorealistic image from a 2D or 3D model by means of a computer program.he term "rendering" is also used to describe the process of calculating effects to produce the final graphical output (Gollent 2014). The use of this term was referenced by a SME in the simulation community in light of the necessity for high quality computer graphics. “Rendering” power and high quality “Texturing” facilitate high quality visual outputs as demonstrated by the results displayed through this qualitative study’s output (Figures 14 and 15). This comes as little surprise given the necessity of modeling and simulation experts like GeoI_3 to ensure environments appear to be true to life for the digital objects they depict.

Figure 14. Breakdown of coded term “Rendering” by SMEs

Figure 15. Breakdown of references to coded term “Texturing” by SMEs

Digital 3D objects emerge in a variety of file formats which require high powered computer graphics-based capacities. This ensures they are displayed in a visually appealing and accurate depiction of a simulated natural or urban environment. GeoI_4 provided specific examples of the use of these programming languages to provide real-world inspired design, lighting, and texture to graphical output:

“With file formats like GLTF or USD or MaterialX that have those physical principles in the materials, you start to have things that look correct in any physically correct lightening environment. That's a big workflow advantage whether you're doing game developments or even things that aren't obviously physically-based rendering like the animated styles in a Pixar film are still using those principles to make their workflows much, much better.” (GeoI_4)

3D data types such as those mentioned by GeoI_4 have driven the need for high performance computing power systems. To make use of these file types and display them appropriately, computing power and graphics processing is necessary. As 3D geospatial data becomes more widely used within the game development space, high powered computing performance becomes even more necessary to support it. GeoI_4’s sentiments regarding the rendering of polygonal data for high-level performance were echoed by experts in the gaming domain. One example is VGI_3 describing graphics processing operations, such as the display of accurate lighting in environmental displays:

“…there are all kinds of different trade offs, right? If you want to preserve the silhouette of the object, that uses a different technique than if you want to preserve the overall look. You've got to worry about how light strikes a thing because it's one thing to get light in one environment, but then the environment changes and you've got to make sure that the polygons and normals are all facing in the right direction and the reflections work the same...” (VGI_3)

Preserving data integrity and optimizing the ability to manipulate or, in the case of VGI_3’s, provide lighting to 3D objects is a computer graphics intensive process. The shared challenges and methodologies associated with creating simulations of environments in a geospatial or gaming context requires an understanding of how graphics processing hacks can be used to tackle problems.

“Texturing” is frequently used in the game development and technical game art domain. It is of particular importance in considering detailed 3D geospatial data. “Texturing”, as coded in this study, refers to the process of adding a surface texture to a 3D surface of an object (Marschner 1998; Wei 2004). Graphics processing is important in understanding how these processes can be applied within the context of 3D tiles and tilesets, both of which require texture mapping processes. GeoI_4 describes the mechanics behind the application of texturization to surfaces: “With elevation data and imagery…you just generate polygons, and you put the images, and you assign textures, texture coordinates to those polygons so that you've got the image on it.”

The texturization process, when given within coordinate-based terms, describes how practitioners within GIST have harnessed graphics processing tools to successful application in a geospatial context. While the complexity behind the application of specific textures to 3D tile-sets is out of scope for this study, increasing use among GIS technologists of 3D datasets, systems, and tiles has further allowed GISci technology to garner benefit from research surrounding texturing in “graphics” research. Much of this is derived from the body of knowledge surrounding graphics processing in the game development community.

Chapter 5 Conclusion

5.1. Research Questions and Methodology

This paper sought to identify the methodologies and workflows employed by those within the gaming and geospatial arenas, with attention paid to the commonalities and differences within the fields. The methodology consisted of two main components; 1) qualitative analysis using NVivo software of interviews with 16 Subject Matter Experts (SMEs), 2) extensive literature review and research surrounding the 37 coded terms referenced thematically across interviews within the NVivo software platform. SMEs were chosen to achieve an equitable split of responses from geospatial academic, geospatial industry, gaming academic, and gaming industry-based respondents. Interview questions derived from the literature specific to the professional or research-based orientation of the respondent were crafted in advance of all interviews. Standard qualitative tools were used to assess the information gathered through the SME interviews (Edwards-Jones 2014). The qualitative tools within the NVivo software were used to analyze interviews with respondents include but are not limited to; Cohen's Kappa's singular-rater reliability testing to ensure homogeneous codification of qualitative output from the outset, word frequency testing, and network/organizational discourse analysis (Hoover et al. 2011; Kim et al. 2016). The emphasis placed on particular NVivo codes with interview files were directed based upon recurring thematic and relevant recurring concepts of note derived from extensive research and comprehensive literature review involving these concepts.

5.2. Summary of Findings

The major takeaways from the results of the analysis are as follows. The desire to develop and create real world environments has driven the gaming and geospatial arenas together as the will to create geospecific as opposed to simply geotypical renditions of game space has grown. This phenomenon can largely be credited to the simulation community within the gaming sphere, given the necessity inside that community to create hyper-realistic depictions of real-world locations (Evans 2002; Keil et al. 2021). According to both industry and academic leaders, the geospatial body of knowledge can benefit from the game development community in a multiplicity of ways. For one, the emphasis placed upon high performance computer graphics to render high quality visual outputs of 3D data at high frame rates is of increasing importance to the geospatial community in visualizing detailed and accurate geographic depictions at a local and global scale. The development of real-world structures based on geographically-oriented data and/or 3D models demonstrates an important point of exchange between the geospatial and gaming communities. Where game developers might have otherwise been forced to develop new 3D structures from scratch, mimicking the methodology in place for geospatial developers has allowed for tremendous leaps and bounds in graphical generation in both fields.

The geospatial community has by the same hand learned from some of the technical methods put into place by game developers.

To that end, advances in hardware-based GPU-accelerated computing power will help facilitate the adoption of high-level graphics processing for the GISci and game development communities alike (Owens et al. 2008). Moreover, the inclusion of 3D data into GIS software platforms such as Esri's ArcGIS CityEngine further promulgates the need for geospatial developers to look to the game development community (whose workflows often require the need for 3D manipulation tools such as Maya, 3Ds, or DigitalMax) for strategies to help work with 3D spatial datasets without compromising data integrity (Laksono et al. 2019). To that end, many of the challenges described in the literature, and echoed by geospatial industry and academics, described the need to adopt game development's methods of mitigating and managing challenges related to differential spatial data types within the same software system, in addition to issues working with large-scale spatial datasets (i.e., satellite imagery, globally-derived attribute data, point-cloud data etc.). A solution to issues of data handling and integration was expressed by game development SMEs, seemingly in response to the differential data type and massive geospatial dataset processing challenges described by geospatial interviewees. This solution was expressed through the description by many of the interviewees within the gaming arena regarding the use of game engines and the high-level processing power of game engine software such as Unity or Unreal Engine in rendering and working with large datasets. The increasing desire of game developers to help incorporate real world data into game engines within their own technical workflow will help lead the way for the GIST community to similarly work with this data.

5.3 Limitations

Efforts were made to represent all aspects of the gaming and geospatial development industries, but ultimately the interviewee's were those who responded to the request for an interview. While effort was to target SMEs from arenas with lesser coverage (specifically in this case those coming from academic gaming backgrounds), interviews were curtailed by the limited time period for interviews conducted in service of this study and further limited by the degree to which SMEs within a given arena responded (or did not respond) to requests. While 40 requests were sent to SMEs, a total of 16 interviews were conducted. The inclusion of SME across the academic and industry-based communities for these two fields was, as with related qualitative research studies, tied to the number of respondents available to share their input for the study.

5.4. Future Areas of Research

Exciting things lie ahead for the GISci community as a result of the technical methodological exchange with the game development community. The codification of the phrase "Technical Advancements" points to the potential for further cross-collaboration between the geospatial and gaming domain as the rate of technology continues to progress.

The relationship shared between the game development community and computer graphics field and body of knowledge will provide more detailed visualization, texturing, and shading for graphics content in the geospatial and gaming domains. Namely, the use of satellite imagery and real-world geospatial data to create game environments will continue to draw the two domains together as time goes on. Future work should be conducted to present concrete financial incentive to AAA game developers, designers, and environmental/technical art teams within game developments to further substantiate the benefits of bringing in geospecific data to ease the financial cost of building game-worlds from scratch using pre-existing geographic depictions of land to game environments. As time progresses it may be of interest in future research to see how the role of environmental artists within game development transforms to leverage and augment their workflows considering the rise of geospatial data and geographic data processing within game development. To that point, the countless parallels between GIST and game development may have a substantive impact in the future of workforce development in both fields who may derive significant benefit from utilizing the skillsets of technologists to improve the workflows necessary for both fields and future research should be conducted to understand how skilled labor pools from these domains can be targeted to expand the output and demographics within these uniquely intertwined professional arenas.

Moore's Law holds that the transistors in a dense integrated circuit (the hardware needed to enable high level graphics processing at scale) doubles every two years. Advances in GPU technology will provide a means by which to address global-scale rendering within the geospatial community and future research should be pursued with reference to the manner in which high-quality graphics processing will help aid global-scale outputs of geospatial data and information.

Given the emphasis placed on the impact of game engine technology by respondents in this study, attention and research should be pursued in light of the upcoming release of Unreal Engine 5. Specifically, the impact of Unreal Engine 5's Nanite Virtualized Geometry system stands to disrupt game engines' ability to process complex virtualized geometrical systems and achieve pixel scale quality. It should also be noted that the adoption of machine learning and artificial intelligence (themes both expressed in-depth by SMEs) will accelerate the output of technologists in both domains. This cannot be overstated and will also be accelerated through advances in graphics processing GPU-providers from industry leaders such as Nvidia and Intel.

Finally, the desire within the developer community to pursue Open-Source projects and technical solutions is of critical importance in expanding the degree and scope of exchange between these two industries. Open-Source software has already begun to build a bridge between the two arenas in providing free and open access to software projects and the methodological processes for developers in both domains to benefit from. Future research should be devoted in order to understand the points of exchange between the two fields driven by the availability of

Open-Source projects and information from gaming-derived to geospatially-oriented software projects and vis-a-versa.

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