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THE ARCHAEOLOGY OF THE POSTINDUSTRIAL: SPATIAL DATA INFRASTRUCTURES FOR STUDYING THE PAST IN THE PRESENT

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THE ARCHAEOLOGY OF THE POSTINDUSTRIAL: SPATIAL DATA
INFRASTRUCTURES FOR STUDYING THE PAST IN THE PRESENT

By

Dan Trepal

A DISSERTATION

Submitted in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

In Industrial Heritage and Archaeology

MICHIGAN TECHNOLOGICAL UNIVERSITY

2019

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This dissertation has been approved in partial fulfillment of the requirements for the Degree of DOCTOR OF PHILOSOPHY in Industrial Heritage and Archaeology.

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To Joe and Mary

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PREFACE

CO-AUTHORSHIP STATEMENT

The following dissertation contains a manuscript that has been published in a peer-reviewed journal. Dan Trepal was the principal and corresponding author for the manuscripts. Dr. Don Lafreniere, Dr. Jason Gilliland, and Dr. Sarah Fayen Scarlett served as co-authors providing guidance, supervision, and review of the manuscripts. The following citations are provided to indicate the destinations of the manuscripts:

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ABSTRACT

Postindustrial urban landscapes are large-scale, complex manifestations of the past in the present in the form of industrial ruins and archaeological sites, decaying infrastructure, and adaptive reuse; ongoing processes of postindustrial redevelopment often conspire to conceal the toxic consequences of long-term industrial activity. Understanding these phenomena is an essential step in building a sustainable future; despite this, the study of the postindustrial is still new, and requires interdisciplinary connections that remain either unexplored or underexplored.

Archaeologists have begun to turn their attention to the modern industrial era and beyond. This focus carries the potential to deliver new understandings of the industrial and postindustrial city, yet archaeological attention to the postindustrial remains in its infancy. Developments in the ongoing digital revolution in archaeology and within the social sciences and humanities have the potential to contribute to the archaeological study of the postindustrial city. The development of historical GIS and historical spatial data infrastructures (HSDIs) using historical big data have enabled scholars to study the past over large spatial and temporal scales and support qualitative research, while retaining a high level of detail.

This dissertation demonstrates how spatial technologies using big data approaches, especially the HSDI, enhance the archaeological study of postindustrial urban landscapes and ultimately contribute to meeting the “grand challenge” of integrating digital approaches into archaeology by coupling reflexive recording of archaeological knowledge production with globally accessible spatial digital data infrastructures. HSDIs show great potential for providing archaeologists working in postindustrial places with a means to curate and manipulate historical data on an industrial or urban scale, and to iteratively contextualize this longitudinal dataset with material culture and other forms of archaeological knowledge. I argue for the use of HSDIs as the basis for transdisciplinary research in postindustrial contexts, as a platform for linking research in the academy to urban decision-makers, and for more meaningful and effective engagement with broader society.

Keywords: Archaeology, Big Data, GIS, Heritage, Historical GIS, Postindustrial, Spatial Humanities, Urban

INTRODUCTION

The meaning of the “postindustrial” has evolved far from its technical and naïvely optimistic origins in economic literature over the last forty years (Vogt, 2016). Once a descriptor for an economy and society freed from the drudgery and poverty of factory labor to instead pursue creative endeavors, the term *postindustrial* is now more often applied to places where industry has failed or fled; the postindustrial landscape is a ruinscape, the shattered evidence of modernity’s failure to realize its utopian dreams (Harrison, 2011; Millington, 2013). Conflicting identities, vast inequality, ruins, aging infrastructure, environmental damage – these common features of postindustrial places often set the stage for conflict between the communities who inhabit them and the forces and institutions of the neoliberal global economy that seek to “regenerate” the postindustrial city in ways that tend to reinforce inequality and injustice (Neumann, 2016; Mallach, 2018).

Postindustrial landscapes are also quintessentially archaeological; they are places where a complex, multithreaded past world – uncomfortable and yet often romanticized –physically intrudes upon us, often in spite of our best efforts. The scale of this intrusion matches the enormity of the industrial revolution, the evolution of which created new networks of people and things that fundamentally shaped human life over the last two centuries. How do we study these complex postindustrial places? What contributions can archaeologists make to the study of the postindustrial, the legacy of long-term processes of industrialization and deindustrialization that present us with a rich (if tantalizingly incomplete) historical and archaeological record?

Archaeology originated as the study of the ancient, “lost”, and distant past through material remains. While materiality remains a central focus of the discipline, archaeologists have continued to reflexively explore the boundaries of their mandate, redefining the meaning of the “ancient” and the “material”. Archaeologists are increasingly turning their attention to more recent eras, so that we now increasingly speak of the archaeology of the modern era, of the recent past and even the archaeology of the present. Likewise, some archaeologists are increasingly looking to ground the

relevancy of the discipline in its ability to confront contemporary issues through an understanding of their past preconditions (Mrozowski, 2014). These developments challenge many of archaeology's basic assumptions about how we do archaeology and our purpose in doing it. By conceptualizing archaeology in these ways, we challenge ourselves to use archaeology as a means of actively intervening in contemporary social life. This is a more politically aware archaeology, and discussions of how to best accomplish this are set to continue for the foreseeable future. No archaeological context encapsulates this challenge better than postindustrial places.

These epistemological discussions also carry methodological challenges. Industrial and postindustrial contexts are large in scale and physically complex. Archaeologists must also reckon with a historical record that becomes increasingly voluminous as we move towards the present, even though (as with all evidence of the past) both the material and documentary records are always fragmentary. This dissertation draws in particular on methodologies developed within industrial, urban, contemporary, and public archaeology; each contribute to the study of postindustrial places by seeking to expand the practical scale of archaeological inquiry in different ways. Each also offers lessons about how to integrate historical documentary evidence into archaeological work. Finally, each offers different insights on the ways we may democratize the discipline through both more transparent and reflexive knowledge production practices and a greater commitment to engagement with, and participation from, outside the discipline. Among archaeologists, we also see a growing realization that the digital realm represents a promising avenue for meeting these challenges and pursuing the aforementioned goals, though the digital revolution within archaeology itself is far from complete and faces substantial obstacles that must be overcome (Kintigh, 2006; Snow et al., 2006; Llobera, 2011; Huggett, 2013; Murray, 2013; White, 2013; Huggett, 2015a, 2015b; Reilly, 2015; Dallas, 2015; González-Tennant, 2016). How should archaeologists approach the scale of industrial and postindustrial landscapes? How can we make the best use of the fragmentary archaeological and historical records connected to these places? What is the most appropriate role for digital technologies within this context?

This dissertation approaches these challenges to archaeology using spatial digital methods developed both within the discipline and elsewhere within the social sciences and humanities. The emergence of Historical GIS (HGIS) and Historical Spatial Data Infrastructures (HSDIs) in particular has permitted social scientists and humanists to study the past spatially, at ever greater scale and detail, using historical big data in the form of large bodies of historical records digitized and stored as geodatabases that can easily be shared across any computer network (Gregory, DeBats, and Lafreniere 2018). At present, archaeologists working in historical contexts still use GIS primarily as a tool of cartography and database management, not as a digital *infrastructure* that supports curation, visualization, analysis, dissemination and public participation. While archaeologists elsewhere within the discipline have taken some important steps in this direction, the focus remains on linking existing collections and supporting access to researchers. The adoption and use of some form of archaeological spatial data infrastructures thus remains in its infancy. Dallas (2015) has identified the large-scale development of such infrastructure as a “grand challenge” for archaeology.

By demonstrating a next-generation spatial data infrastructure for archaeology, I aim to demonstrate the ways in which spatial digital technologies using big data enhance the archaeological study of postindustrial places. To do this, I present several case studies demonstrating how the use of historical Big-Data-based HSDIs by archaeologists working in postindustrial contexts aids in the expansion of the scale of archaeological inquiry; how historical big data can be used to better understand historical processes of industrial hazard accumulation that represent a crucial, but poorly understood aspect of contemporary postindustrial urban landscapes; and how HSDIs infrastructures may be used by archaeologists to help foster more effective ties with community heritage-making. These three case studies represent an introduction of the HSDI as a key component of the archaeological study of postindustrial places. As such, they illustrate the potential use of the HSDI for more ambitious work within a more developed archaeology of postindustrial places going forward.

I argue that any archaeology of the postindustrial must be interdisciplinary and eclectic, juxtaposing the material and human, the digital and analog, and the past,

present, and potential futures. This is because the postindustrial landscape itself is a contemporary landscape composed of a dynamic, inseparable blend of each of those attributes; no period study framework or single set of disciplinary theory and method can hope adequately address the archaeology of the contemporary landscape (González-Ruibal, 2008; Holtorf and Piccini, 2009; Harrison, 2011; González-Ruibal, Harrison, Holtorf, and Wilkie, 2015). While I focus on digital methods in my research, the overriding motivation driving this research is to facilitate a better connection with, and understanding of, *people* and *things*, or human-nonhuman assemblages and interactions, across time; an “analog” connection with physical remains, sites and landscapes at some level remains fundamental. With that being understood, I argue that the use of digital tools can and should augment this process by allowing us to look at archaeological and historical data in new ways and in new contexts. Finally, and most importantly, digitally augmented archaeology of the postindustrial is bent towards democratizing the study of the postindustrial landscape by making archaeology more transparent, flexible and accessible to the public. This places archaeology at the forefront of the study not only of the past, but also of our understanding of the past’s influence on the present and future.

LITERATURE REVIEW/THEORETICAL CONTEXT

Postindustrial landscapes represent an exciting but underexploited laboratory for archaeologists. While historical, urban and industrial archaeologists have turned their attention to the archaeology of the industrializing and industrialized world, very little work has been explicitly undertaken to explore the material aspects of the postindustrial world, even though deindustrialization can itself now be fairly termed a historical process. While not always explicitly targeting the postindustrial, several developments in archaeological theory have called for a closer relationship between archaeology and the recent past, present, and even future that is relevant to the study of postindustrial places.

This literature review identifies several archaeological subdisciplines that have identified the need for greater temporal and spatial flexibility within archaeology, with the ultimate goals of making the discipline more transparent, democratic, and socially relevant to our own and future society. Archaeologists have increasingly argued for a

more effectual embrace of the digital revolution as one crucial means to achieve this, yet several branches of archaeology that are potentially well-poised to answer this call lag behind in their adoption of digital archaeology approaches. To remedy this, I turn to digital scholarship elsewhere in the social sciences and humanities. Here, innovative approaches to the use of GIS for the study of the past have resulted in spatial digital infrastructures that could be adapted to include archaeological knowledge and the archaeological process. In adopting such approaches archaeologists may expand the spatial and temporal scope of their research, enhance interdisciplinary collaboration within the social sciences and humanities (and beyond), and ease the task of sharing this knowledge with or enable participation by professionals and the public. The linkages between industrial archaeology, urban archaeology, contemporary archaeology, public archaeology on the one hand, and historical GIS, GIScience, spatial history and the digital humanities on the other forms the fundamental theoretical context for my research.

POSTINDUSTRIAL PLACES

The postindustrial landscape is a unique feature of the “late modern” (Harrison, 2013) or “supermodern” era (González-Ruibal, 2008); it is the result of deindustrialization processes that radically re-shaped many cities in the latter half of the twentieth century. In North America, foreign competition and American industrial complacency after World War II led to widespread factory closure and job loss, especially in the worn-out industrial cities that became poster children for deindustrialization (Bluestone & Harrison, 1982; Cowie, Heathcott and Bluestone, 2003; High, 2003; Mallach, 2018). New migration patterns, especially parallel episodes of African American in-migration and white flight, accompanied the decline of manufacturing, resulting in the replacement of communities of industrial immigrant or white labor by new working class immigrant and minority groups; these groups found themselves living adjacent to abandoned industrial sites and brownfields (Goldfield & Brownell, 1991, pp. 375-377; Sugrue, 1996). Cities specializing in heavy industries such as steel (Cleveland, Youngstown, and Pittsburgh), and automobile manufacturing (Flint

and Detroit) were among the hardest hit by these processes (Goldfield & Brownell, 1991; Dandaneau, 1996, Steinmetz, 2009; Mallach, 2018). Outside the large industrial centers other communities, most notably mining towns, also suffered a dramatic downturn in fortunes (Robertson, 2006). Deindustrialization has left us with “traumascapes” (Tumarkin, 2010) of decay, abandonment, injustice and poverty, perhaps best encapsulated by Jerry Herron, writing of Detroit: “Nowhere else in this country has so much history, both human and material, been reduced to a dreadful and frightening inconsequence” (Herron, 1993, p.208). Since the late 1990s, many post-industrial cities have sought recovery through environmental remediation and a shifting of focus to the knowledge economy and tourism, though the impacts of this process have been both spatially and economically uneven (Kirkwood, 2011; Mallach, 2018; High, MacKinnon, and Perchard 2017).

ARCHAEOLOGIES OF THE POSTINDUSTRIAL LANDSCAPE: APPLICABLE THEORIES

The academic study of deindustrialization and the postindustrial remains an emergent field (High, 2013), and archaeology is no exception; explicit archaeological interest in the postindustrial is most often encountered in the context of industrial heritage preservation efforts (Douet, 2015). Despite this, three archaeological sub-disciplines have conducted work in postindustrial places, or have developed new ways of doing archaeology that are potentially well suited to these contexts: industrial archaeology, urban archaeology, and contemporary archaeology. Industrial archaeology recognizes the need for scales of archaeological inquiry appropriate to the subject matter, calls for a firm understanding by archaeologists of the technical and social features of industrializing and industrialized societies, and embraces the value of industrial heritage for the practical application of archaeological knowledge.

Urban archaeology also recognizes the need for spatially expanded scales of inquiry, stresses the need for close integration of historical source material, and argues for archaeology as a source of social justice through archaeologically informed counter-narratives and the study of marginalized peoples. Contemporary archaeology pushes the

archaeological remit forward to the (postindustrial) present and future and suggests innovative, even radical new ways of conceptualizing the relationship between the time, people, and things through an archaeological lens. Both urban and contemporary archaeologies trace their roots to several specific strains of processual archaeology (though neither is itself processual in approach): ethnoarchaeology, modern material cultures studies, and Bill Rathje's garbology (Rathje 1979; Gould & Schiffer 1981). Modern material culture studies and garbology pushed the temporal remit of archaeology forward into the modern era, and even toyed with applications of archaeology in the present and future (Rathje, 1979). While postprocessual theorists criticized many aspects of these early forays into the archaeology of the contemporary, the recognition of modern contexts as valid or even necessary subjects of archaeological research survived the paradigm shift (Hodder 1987; Shanks & Tilley 1992; see also Harrison 2011). Building on this, industrial, urban and contemporary archaeology have each subsequently carved out distinct – though not always mutually exclusive – spaces within the canon of archaeological theory, and elements of all three underlie my approach to the archaeology of postindustrial cities.

INDUSTRIAL ARCHAEOLOGY: UNDERSTANDING INDUSTRIAL SCALES, PROCESSES, AND HERITAGE

Industrial archaeology, a hybrid of archaeology and heritage, occupies a relatively small niche within the academy, especially within the United States; yet its contributions are crucial to any archaeology of the postindustrial. Industrial archaeology first appeared in the United Kingdom in the 1950s and 1960s as the result of an alliance of amateur historians and historians of technology interested in preserving artifacts and buildings associated with the early industrial revolution period (Rix, 1955; Green, 1963; Hudson, 1963; Martin 2009). Industrial archaeology in this form quickly developed a close relationship with heritage preservation and management organizations such as English Heritage, the UNESCO World Heritage Convention (WHC), The International Committee for the Conservation of Industrial Heritage (TICCIH), The International Council on Monuments and Sites (ICOMOS) (Trinder, 2015, pp. 24-25). In the United

States, the National Park Service (NPS) and Historic American Engineering Record (HAER) performed similar work, but it was not until the 1980s and 1990s that American academics began to publish self-identified “industrial archaeology” scholarship (Martin, 2009).

Beginning in the 1980s, industrial archaeology scholarship began to diverge into several distinct lines of inquiry. One of these, which coalesced in the 1990s, focused on applying archaeological methods to the understanding of industrial revolution-period production processes, engineering and resource use; this often took the form of CRM-style “rescue archaeology” and/or heritage preservation/interpretation at large-scale eighteenth- and nineteenth-century industrial sites (Gordon and Malone, 1994; Palmer and Neaverson, 1998; Cranstone, 2001). Subsequent industrial archaeology research expanded beyond this initial descriptive and production-focused phase to include the social aspects of industrialization, examining wastes and residues as significant in their own right, exploring broader industrial networks at ever-larger scales, and integrating archaeology more closely with heritage preservation and interpretation (Casella & Symonds, 2005; Martin, 2015). Another distinct thread of industrial archaeology emerged in the 1980s in the United States, where a less technocentric structuralist approach became the dominant paradigm (Deetz, 1977, Leone et al., 1987; Orser, 2017). This research became grounded in postprocessual theory and defined industrial archaeology as the study of capitalism, social relations, consumption or consumerism, and the archaeology of the working class (Symonds and Casella, 2006; Orange, 2008). A parallel shift in focus took place in the 1990s in the UK (Palmer and Orange, 2016). Despite this, the more technology-focused strain of industrial archaeology continues to be visible, particularly in the journals *Industrial Archaeology* in the US and *Industrial Archaeology Review* in the UK.

Industrial archaeology thus remains a flexible and diverse field; this is reinforced by the numbers of scholars with an archaeological background publishing prominently in the field of industrial heritage, and by the continued focus within industrial heritage of engaging with the material world (Orange, 2008; Orange, 2014; Douet, 2015; Mieg & Oevermann, 2015; Trinder, 2015). In all of its various manifestations, industrial

archaeology highlights the need to understand the ways in which the industrial revolution fundamentally and irrevocably altered the physical and social landscape wherever it established itself. Industrial archaeologists have demonstrated that many archaeological techniques originally developed for studying prehistoric peoples can be usefully applied to industrial contexts (Martin, 2015) and continue to look for new theoretical and methodological approaches to improve the discipline. For example, industrial archaeologists have recently begun to discuss how digital approaches could be an important way forward, though this process is very much in its infancy (Stuart, 2015; Palmer and Orange, 2016).

Finally, industrial archaeology has served as an important advocate for the significance of the postindustrial landscape through its connections to heritage preservation and interpretation (Cossons, 2015). Development pressures and negative perceptions surrounding these landscapes place them at high risk of loss; yet they remain a critical, understudied archaeological and heritage resource with the potential to provide immense contributions to our knowledge of the past and, more importantly, to the identity and prosperity of present and future communities living in and among them (Cossons, 2015).

URBAN ARCHAEOLOGY: STUDYING THE MODERN CITY

Urban archaeology represents another sub discipline of archaeology that has sought to address the challenges of archaeology in modern, urban contexts. Modern material culture studies and garbology, along with the passage of the National Historic Preservation Act of 1966 (NHPA) served as catalysts for the expansion of historical archaeology into the modern industrial era, resulting in the emergence of urban archaeology as a distinct sub-discipline in the late 1970s (Dickens, 1982; Cantwell, & Wall, 2001; Rothschild and Wall, 2014). Urban archaeologists conceptualize the industrialized city *itself* as a single archaeological site or artifact; urban archaeology is therefore the archaeology *of* the city rather than simply archaeology *in* the city (Dickens, 1982, p. xix).

Urban archaeologists expand the scale of archaeological inquiry at both macroscopic and microscopic scales (Rothschild and Wall, 2014). This presents unique challenges in terms of the required scale of inquiry and methods to achieve that scale. For example, in conceptualizing New York city as a single archaeological site covering its entire history of occupation, Cantwell and Wall faced daunting issues of physical and temporal scale; they argued that despite these issues a macroscopic view of the city using vast combinations of archaeological and historical evidence could reveal new patterns of very long-term change in cities (Cantwell and Wall, 2001). Conversely, The desire to create highly detailed microhistories of the daily lives of past communities required Murray and Mayne to critically juxtapose archaeological and historical data at fine, even individual levels of detail to provide a counter narrative redefining a nineteenth-century Sydney “slum” as populated with aspirational people working to better their circumstances (Murray and Mayne, 2001).

From a methodological standpoint, urban archaeologist have emphasized the need for urban archaeology to be interdisciplinary, particularly in the close integration of detailed historical research more into archaeological research design, fieldwork, and analysis. Given the dense layering of urban spaces and their tendency to be well documented within the historic record, achieving a closer integration of archaeological and historical research results in 1) better contextualization of both and the identification of new patterns or linkages heretofore invisible, and 2) the ability to critically evaluate different but overlapping bodies of evidence with greater rigor (Dickens, 1982; Cantwell, & Wall, 2001; Mayne and Murray 2001; Rothschild and Wall, 2014; Murray, 2013). Urban archaeologists have also emphasized the research potential of existing archaeological collections, pointing out the expense of excavating and demonstrating that much valuable research (especially reinterpretation or revision) can be wrung out of archaeological collections long after excavation and even publication (Mayne and Murray 2001; Voss, 2012).

Archaeologists working in postindustrial contexts may also take inspiration from urban archaeology’s broad political agenda. This has evolved to focus on the challenging of historical stereotypes about past societies and permitting the formation of counter-

narratives, fueled by archaeological data, that revise and nuance our understanding of cities by amplifying the voices and roles of marginal and disempowered urban dwellers (Mayne and Murray, 2001; Yamin 2001). Urban archaeologists see this as not merely revisionism for revisionism's sake, but as a means of achieving positive social change in the present (Symonds 2004; Rothschild and Wall 2014). Processes such as urban renewal continue to play a role in urban life today and may be critically re-examined through urban archaeology in ways that may directly contribute to current debates on these phenomena (Mayne and Murray, 2001; Ryzewski, 2015).

CONTEMPORARY ARCHAEOLOGY: EXPANDING TEMPORAL BOUNDARIES

Another group of interrelated threads of archaeological thought applicable to the postindustrial may be gathered under the shorthand of "contemporary archaeology" and are relevant to the archaeology of postindustrial places. Like urban archaeology, contemporary archaeology draws inspiration from the notion, first articulated by modern material culture studies (Dickens, 1982) and garbology (Rathje, 1979), that archaeologists can do archaeology in non-ancient contexts and/or without excavating. Contemporary archaeologists take a substantially broader interpretation of this idea than do urban archaeologists, seeing their area of study archaeologies of the recent past (Buchli and Lucas, 2001a; Gonzalez-Ruibal, Harrison, Holtorf, and Wilkie, 2015), or even "archaeology in and of the present" or the *now*, emphasizing a departure from archaeology as necessarily studying the past (Harrison 2011, p. 141).

Contemporary archaeology focuses on the mundane, ordinary, hidden, abject, or even traumatic aspects of modern culture as manifested in the material world. Contemporary archaeologists also take a self-consciously critical approach to their work, casting modernity as a failed or unrealized project often resulting in inequality and injustice, - with archaeology itself a product of modernity and thus implicated in its failings (Thomas 2004; Harrison, 2011). Contemporary archaeologists seek to more closely link the past, present and future through the study of the relationships between things and people across time. Victor Buchli explained this process as "[making] the familiar strange" by applying archaeological methods to contemporary contexts,

enabling the researcher to tease out knowledge that “discursive and textual” methods alone may be incapable of identifying (Gonzalez-Ruibal, Harrison, Holtorf, and Wilkie, 2015, p. 272). Buchli and Lucas demonstrated this with their excavation of a hastily abandoned social housing unit in the UK (Buchli and Lucas, 2001b). By treating the apartment as a “site” and applying archaeological methods, Buchli and Lucas showed how purely archaeological methods can be used to identify and flesh out processes of social marginalization and alienation as well today as in the historical or ancient past.

Some contemporary archaeologists have framed the intermingling of people and things using Actor-Network Theory (ANT) (Fortenberry and McAtackney, 2012) and assemblage theory (Harrison, 2011). ANT is a social theory that focuses tracing the associations between people and objects. A key facet of the theory useful to contemporary archaeologists is the notion that objects hold equal status as actors within the actor-network relationship (Latour, 2005). Existing as an alternative to the previously dominant idea that society can be discussed metaphorically as an organism, assemblage theory instead proposes a framework where heterogeneous groupings (assemblages) of both natural and social phenomena create new entities distinct from the sum of their parts (DeLanda, 2006; Harrison, 2011). ANT and assemblage theory ultimately allow contemporary archaeologists to “flatten” time and conceptualize archaeology as what Harrison calls “surface survey”, the idea that the past, present and future are combined and juxtaposed on one surface – the present (Harrison, 2011). By flattening time, contemporary archaeologists seek to more closely link the past, present and future through the study of the relationships between things and people across time. In doing so, the ultimate goal is to shift archaeological interest in the mundane and hidden into the present, thereby reaching new constituencies and giving voices to otherwise silent groups – not only in the past, but also in the present – that are poorly represented within dominant paradigms (González-Ruibal, Harrison, Holtorf, and Wilkie 2015).

PUBLIC ARCHAEOLOGY: LESSONS FOR ACHIEVING RELEVANCE AND VISIBILITY

As discussed previously, a salient feature of postindustrial places is the social and material inequalities and injustices they harbor. The foregoing developments in

archaeology are aimed at better understanding the lives of past societies in industrial and urban, and contemporary contexts, (especially the absent misrepresented, and marginalized portions of past societies), as well as the processes, many of which remain features of our own society, that underlie these phenomena. This research is not, however, inherently informative to the public or collaborative with living communities. Public archaeology represents a subdiscipline devoted to understanding and developing the relationship between archaeological expertise and society for mutual benefit. If archaeology is to intervene positively within contemporary postindustrial places, we must apply the lessons learned within the realm of public archaeology. Public archaeology's central understanding of meaningful public engagement is the necessity of public collaboration at all stages of archaeological research: design, execution, and interpretation (Klein et al., 2018; Ryzewski and Cherry, 2012; Moshenska, 2017; Bonacchi and Moshenska, 2015; Morgan 2012; Atalay, 2012). Regardless of how sophisticated or useful archaeologists' understanding of postindustrial places becomes, our relevance to broader society remains linked to the degree to which we can meet this standard of public collaboration.

MOVING FORWARD: IDENTIFYING KEY CHALLENGES

In spite of their underappreciated status within archaeology, postindustrial urban spaces represent ideal laboratories for archaeology. No other archaeological context features a clearer link between past activity, contemporary consequences and the potential influence of both on the future. The socially stratified (yet densely populated) nature of cities magnifies these qualities and makes them especially useful for studying issues of inequality and social justice. Both urban and contemporary archaeology are explicitly committed to Shanks and Tilley's succinct summation of postprocessual archaeology's ultimate purpose as a "critical intervention in contemporary society...with transformative intent", and industrial archaeology has increasingly embraced broadly similar goals (Shanks & Tilley, 1992 p.172, Casella and Symonds, 2005; Douet, 2015). All three push the remit of archaeology forward in time into the modern era and beyond without losing sight of the constant presence and influence of

the past. Each has made important methodological innovations suitable for work in postindustrial cities. Industrial archaeologists recognize the need for the application of archaeological methods appropriate to the scale of industrial contexts and industrial processes, and the need for close connections with heritage-based public outreach. Urban archaeologists have expanded the scale of archaeological inquiry to the level of the city or beyond –archaeology *of* the city as a discrete artifact, though traditional archaeological methods limit the extent to which this can be achieved in practice. They have recognized that the closer, reflexive integration of historical source material with archaeological remains serves as both an informer of archaeological research and a human narrative to be questioned and critiqued using both historical and archaeological evidence. Contemporary archaeologists have argued for a more expansive understanding of what constitutes an archaeological site – looking at more temporally diverse assemblages of past and present people, objects and places rather than discrete artifact collections and sites (Harrison, 2011). Finally, public archaeology challenges us to move meaningfully beyond the academy and reminds us of the consequences of failing to do so (Klein et al., 2018).

Taken together, these theoretical and methodological threads form the foundations of what the archaeology of postindustrial urban places should look like, and help identify key challenges towards successfully doing archaeology in postindustrial contexts. Postindustrial archaeology adopts an expanded *spatial and temporal* scope over previous archaeological work. The past, present, and future are also more tightly bound together through material and historical evidence; the knowledge gained from this process should be applied so as to bring about positive social change by challenging assumptions and conventional narratives (or raising new questions) about the past and present through the study of material remains and historical sources. From a methodological perspective, the key challenges to achieving this greater spatial and temporal scope include 1) finding more effective methods to capture and study the industrial/postindustrial archaeological record at varying scales; 2) Demonstrating how juxtaposed pieces of evidence of the past, each with unique temporal bounds, manifest themselves in the present and can be linked with “lost” landscapes or populations at

different periods in the past; 3) Linking this complex record to the postindustrial communities, places, and attendant social issues occupying the same *space* today.

A fourth challenge must be added to these: dealing with the longstanding, unresolved, and growing global “curation crisis” in archaeology, (Marquardt, Montet-White, and Scholtz, 1982; Childs, 1995; Bustard, 2000; Bawaya, 2007). While archaeological fieldwork is typically described as a way to recover and preserve a record of the past, much of this record is allowed to pile up, ignored, in archives and warehouses in the form of artifact collections and paper excavation records; in many cases these collections of archaeological data are “orphaned”, left without a responsible party to curate them (Voss, 2012). Worse, this process is accelerating, driven to a great extent by land development activity operating under federal historic preservation regulations that mandate and support archaeological “compliance projects” to the tune of over a billion dollars annually that produce a “tsunami of reports” that are often very difficult to access (Kintigh et al., 2015, p. 3).

Addressing these four challenges requires an expansion of the scale and flexibility in archaeological research, curation and outreach; below I argue that this is best accomplished by the adoption and adaptation of specific digital methodologies and techniques, in use both within the discipline of archaeology and without. While the value of digital technologies is broadly recognized within archaeology, “digital archaeology” remains a rapidly evolving, poorly defined area despite a growing consensus that it is indispensable to the field. Before identifying the specific approaches postindustrial archaeology should use, we review the state of “digital archaeology” in order to see how archaeologists have approached the challenges mentioned above, and how a more interdisciplinary approach to the archaeology of postindustrial urban spaces can better meet the standing challenges of our theoretical context.

DIGITAL ARCHAEOLOGY: UNTAPPED POTENTIAL FOR POSTINDUSTRIAL CONTEXTS

COMPUTERS AND ARCHAEOLOGY – A BRIEF HISTORY

For decades, the nature of the relationship between the discipline of archaeology and digital or computational approaches was closely intertwined with the debates over

the utility of quantitative research within the discipline. The first applications of computers to archaeology applied statistical thinking to artifact assemblages appeared in the 1950s and were most closely associated with processual or “New Archaeology”; based on positivist assumptions about the objectivity of data and the potential of hypothetico-deductive reasoning, processual archaeologists attempted to develop models of entire societies, facilitated by the use of computers (Cowgill, 1967; Aldenderfer 1998; Lock, 2003; Huggett, 2013; Lake, 2014; Simoni, 2016). The ultimate aim of such research was the identification of cross-cultural patterns that could be elevated to the status of universal “laws” of human behavior (Clarke, 1968). Quantitative and positivist-influenced computer-based archaeology research work of this type grew in numbers and variety over the next two decades (Aldenderfer, 1998, Huggett, 2013; Grosman, 2016). The postprocessual critiques of the New Archaeology that arose in the 1980s and 1990s rejected the positivism and quantification of processual archaeology, favoring a much more contextual, reflexive relationship between subject and object, referred to as a “hermeneutic spiral” (Shanks and Tilley, 1987). Digitally based methods popular within archaeology like GIS, with their quantitative underpinnings, were criticized as the product of modern, western scientific paradigms that were incapable of meaningfully representing the worldview of past (or non-western) cultures (Connolly and Lake, 2006). This postprocessual reaction to computer-aided archaeology may also be broadly contextualized within the “science wars” that took place during the 1980s and 1990s as postmodern social scientists engaged in heated debates with scientists over the authority and unity of “science” and the scientific method (Wylie, 2000; Schuurman, 2000; Parsons, 2003). Very few postprocessual critiques came from archaeologists actually using computers extensively, however; instead, computational and digital approaches were collectively targeted by postmodern critics within their broader criticisms of the scientific method and quantitative approaches (Lock, 2003; Lake, 2014), though a few early postprocessualists themselves grappled with the use of computers within the new theoretical environment (Shanks and Tilley, 1987; Hodder, 1999). Postprocessual critiques did not put an end to the use of computers in archaeology, but did result in ongoing debates on the utility of computers in archaeology that led to substantial re-

evaluations during the 1980s and 1990s (Kvamme, 1999; Lake, 2014). As Gary Lock points out in his review of the use of computers in archaeology, the processual and postprocessual stances towards computers are best seen as “useful extremes”; most archaeologists occupy a “pragmatic middle ground” between these (Lock, 2003, p.4).

Some computer-aided archaeological techniques adopted very early on and still in widespread use, such as archaeological predictive modeling (APM) (especially popular within cultural resource management (CRM) archaeology), have persisted in spite of postprocessual critiques, and their practitioners (who tend to be more quantitatively-focused in their research) have gradually worked towards developing less positivist or environmentally-deterministic iterations of their methods rather than fundamentally altering or abandoning them (Lock and Harris, 2000; Verhagen 2007; Verhagen, Nuninger, Tourneux, Bertoncello, and Jeneson, 2013). Other approaches, such as computer-aided archaeological simulation, became deeply unfashionable during the postprocessual era, only to re-emerge later as technological innovations and new theoretical arguments addressed some of the critiques and brought the approach back towards the mainstream (Lake, 2014).

Perhaps most importantly, a number of wholly new or radically enhanced digitally based ways of “doing archaeology” appeared beginning in the 1990s that brought some rapprochement between postprocessual critics and digital or computational archaeology. Most prominent among these were new means of visualization through digital media and the rise of the internet - especially the advent of Web 2.0 technologies that afforded easy collaboration and sharing of information (Webmoor and Shanks, 2008; Ryzewski, 2009; Harrison, 2010; Kansa, Kansa, and Wattrall, 2011); archaeologists exploring these argued that digital technologies, far from being limiting or positivist, could actually serve as aids to more reflexive, transparent and democratized archaeological practice by expanding the definitions of the material to include digital forms, and by fostering wider engagement and participation with archaeological research (Shanks, 1997; Shanks, 2007; Webmoor, 2008; Ryzewski, 2009; Harrison, 2010, Olsen, Shanks, Webmoor, and Whitmore, 2012; Morgan and Eve, 2012).

Noting that traditional methods of recording and publishing archaeological data often concealed or “black boxed” the many intermediate steps involved in the creation of representations, Olsen et al. argued that the “ready-made networks” afforded by digital media can make the archaeological process more transparent and collaborative, rather than positivist or determinist as early postprocessual critiques often averred (Olsen et al., 2012, pp. 127-130). There may also be a generational factor at play in this shift; Krysta Ryzewski has noted that the adoption of digital methods within archaeology is partially driven by a “young, rising generation of archaeologists for whom new media have always been familiar, if not indispensable, components of their everyday lives” (Ryzewski, 2009, p. 365). The rapid evolution and growing integration of such technologies in society made their consideration by archaeologists not merely advantageous but imperative, as articulated by Rosemary Joyce and Ruth Tringham ten years ago: “We do not have the luxury of ignoring these media...a failure to explore them will deprive us of an opportunity to develop new ways of representing archaeology as a multi-voiced, multi-stranded, contingent process” (Joyce and Tringham, 2007, p. 333).

The broad historical trajectory of the role of computers in archaeology can thus be characterized as initial positivist enthusiasm, a fall from fashion in the face of postmodern critiques, and finally a gradual (and accelerating) acceptance - though with ongoing theoretical adjustments and reflections on technological evolution. The most significant effects of the postprocessual critiques were 1) shifting the emphasis towards richly contextual “data-driven exploratory analysis rather than the theory-driven confirmatory deductive methods enforced by data-poor digital models” (Lock, 2003, p. 12); and 2) the exploration and adoption of new digital modes of visualization and participatory involvement by postprocessual archaeologists and their academic descendants themselves, demonstrating that quantitatively-based technologies could serve qualitatively-focused archaeological research. The constant interplay between theoretical development and more rapid technological change has become (and will likely continue to be) a defining feature of the relationship between archaeology and the computer revolution.

SUBSEQUENT TRENDS IN DIGITAL ARCHAEOLOGY: UNCOORDINATED GROWTH

By the end of the 1990s the heterogeneous set of theories, methods, and tools adopted by archaeologists using digital technologies resulted in an equally variegated set of terms describing what had become a loosely defined subfield. Early terms such as *computer archaeology* and *archaeological computing* gave way, after the personal computer revolution and arrival of the internet, to terms such as *cyber archaeology*, *digital archaeology*, and *virtual archaeology* (Huggett, 2013; Grosman, 2016). Of these, “digital archaeology” is the most widespread, though more recently proposed terms such as *computational archaeology*, *archaeological informatics* and *Archaeological Information Science* (AISci) are still too new to track with tools such as Google’s Ngram Viewer (Huggett 2013). Henceforth I will subsume all of these under the term “digital archaeology” for the sake of convenience, but it is worth recognizing here that it is merely the most popular of a number of terms describing a closely related set of approaches, and its adoption is not universal within the discipline at this time.

Mirroring the diversity of monikers, we find an even greater number of methods and techniques currently being employed within digital archaeology, the breadth of which is best represented by the annually published proceedings of recent Computer Applications and Quantitative Methods in Archaeology (CAA) conferences. Perusing the pages of these publications reveals the application of numerous computational methods to archaeological contexts, organized into broad categories spanning the full breadth of digital/computational techniques and methods currently being employed by archaeologists such as data collection, data analysis and management, data dissemination, and cultural heritage management (usually referred to as Cultural Resource Management (CRM) within the United States) (Traviglia, 2014). Under “Data collection” we find techniques such as remote sensing, satellite photo-based prospection, 3D scanning, digital photogrammetry, and paperless site recording methods (Traviglia, 2014). “Data analysis and management” includes agent-based modeling, simulations, mathematical morphology analyses of lithics, least-cost path analysis, spatial statistical analysis for dating pottery, predictive modeling, and digital cataloging & archives

(Traviglia, 2014). “Data dissemination” covers 3D modeling, game engine-based visualization, virtual reality, digital reconstructions, automated artifact classification methods, and the digital reconstruction of fragmentary artifacts. “Cultural Heritage Management” includes cultural property inventory databases (Traviglia, 2014). It is clear that the archaeological use of these and other digital approaches are here to stay; In her recent review of the computational revolution’s impact on archaeology, Leore Grosman argued that archaeological documentation “has reached the point of no return...and reverting to traditional methods is highly improbable” (Grosman, 2016, p. 129).

While this variety of terms and even wider variety of techniques and methods demonstrates a broad and ongoing adoption of digital approaches within archeology, it also reveals something of a crisis of identity. Citing a recent assessment of the term “digital humanities” as one of “tactical convenience”, Huggett suggested that the newest terms describing the use of computer technologies in archaeology (such as *digital archaeology*, *computational archaeology*, *archaeological informatics* and *Archaeological Information Science*) served a similar function as a means to attract funding, or to “get things done” first and foremost, rather than as rallying points for a coherent subfield (Kirschenbaum, 2012; Huggett, 2013). Linked to this is the fact that, despite having appeared over half a century ago, computational or digital archeology is still often referred to as an “emerging” field by its practitioners (Huggett, 2013). This inability to move beyond “emergent” status suggests an ongoing internal dissatisfaction with the current state and influence of digital archaeology (e.g. Llobera 2011) that represents a symptom of an “anxiety discourse”. Huggett (2013) characterizes anxiety discourse as a chronic questioning of the “identity, nature and academic legitimacy of the field” (p.15), stemming in part from the perceived tendency of a field to be focused on praxis, borrowing theory and concepts from other disciplines: critiques that have followed digital archaeology for decades (Aldenderfer, 1998; Lock, 2003; Llobera, 2011; Huggett, 2013). This has resulted in ongoing concern and debate over focus and identity, and the repetitive process of re-naming of the field as multiple scholars attempt to define it more clearly (Huggett, 2013).

THE “DATA AVALANCHE” AND GRAND CHALLENGES

The need for a more coherent conceptualization of digital archaeology’s role in the discipline is made especially urgent by the continual expansion (or intrusion) of computer technology into our everyday lives. In parallel with the “curation crisis” of the physical or “analog” archaeological record (including Kintigh’s “tsunami” of CRM grey literature), a side effect of the growing enthusiasm for digital archaeology is an accelerating “data avalanche” or “data deluge”, as the accumulation of digitized data reaches unprecedented proportions; others have also spoken of a “data explosion” as the size of digital datasets themselves have grown from kilobytes, to megabytes, to terabytes and beyond (Petrovic et al., 2011, p. 56; Niccolucci and Richards, 2013, pp. 73-74; Bevan, 2015, p.1473). While this can be contextualized within a broader “data intensive paradigm” (Bell, Hey, and Szalay, 2009; Hey, Tansley, and Tolle, 2009; Bevan, 2015) emerging across the sciences in general, the ongoing growth of the use of computers in archaeology presents its own specific challenges that must be addressed within the discipline.

Over the last decade, some archaeologists have responded to both the “curation crisis” and the “data avalanche” by calling for and developing “distributed disciplinary information infrastructures” or “cyberinfrastructures” (Kintigh, 2006, p.567; Snow et al., 2006). The most successful of these are the Archaeology Data Service (ADS) in the United Kingdom and the Digital Archaeology Record (tDAR) in the United States (Richards, 2008; McManamon, Kintigh, and Brin 2010; Kintigh and Altschul, 2014). These currently function as data repositories or portals, accessed through the internet, for the long-term storage and dissemination of archaeological research materials. Designed initially to handle simple formats such as scanned copies of reports, databases and spreadsheets, these repositories are now also capable of storing and sharing GIS data (such as shapefiles, geodatabases and georectified images), remote sensing data, and 3D scans (McManamon, Kintigh, and Brin 2010; The Digital Archaeology Record, 2017; Archaeology Data Service, 2017). Despite the appearance of such valuable infrastructures they have so far been largely ignored by most archaeologists (Kintigh, 2006; McManamon, Kintigh, and Brin 2010), are for the most part incapable of

visualization or analysis, and also fail to facilitate the documentation of the “complete knowledge creation process” that goes beyond the traditional suite of archaeological records (Dallas, 2015, p. 179).

In an influential critique of digital archaeology within this context, Marcos Llobera argued that the widespread use of information systems in archaeology was proceeding in the absence of a “well-established subfield in archaeology” (Llobera, 2011, p. 216). In a review of current visualization techniques in archaeology, Llobera criticized digital archaeology as under-theorized, focused on the narrow implementation of existing technologies borrowed from elsewhere, and lacking in clear research paradigms or curricula within archaeology. In short, digital archaeology was failing to drive archaeology itself forward in any meaningful way. Llobera articulated the core issues in a series of questions (emphasis mine): “We are able to record information much more quickly in the field but to what degree is this “new information”? How much has it changed the way we conduct our analysis? *We have the capacity to process and visualize information in novel ways but are we actually doing this? ... Has the introduction of information systems precipitated new ways of doing archaeology?*” (Llobera, 2011, p. 217).

One notable response to Llobera’s critique has been a call for the issuance and pursuit of “grand challenges” to better contextualize digital archaeology’s role within the broader discipline and clarify its theoretical framework (Huggett, 2013); this call is only now beginning to be taken up (Huggett, 2015a; Huggett, 2015b; Reilly, 2015; Dallas, 2015). Some envision grand challenges in relatively specific technical terms, such as Paul Reilly’s argument that additive manufacturing (more commonly known as 3D printing) technology has the potential to disrupt archaeologists’ definitions of the terms “*real, virtual and authentic*” (Reilly, 2015, p.228). Reilly, long a proponent of digital, virtual preservation (Reilly, 1991), proposed a fusion between the descriptive language of digital 3D printing file formats and archaeological field context records that could eventually enable “refabricated excavations” (Reilly, 2015 p. 233) at very fine levels of detail – mitigating the destructive nature of field excavation and making excavations and

artifacts more stable and more portable in the form of printable digital code (Reilly, 2015 p. 229).

Most approaches to the grand challenge concept eschew or de-emphasize focusing on any specific technical approach; instead they focus on the ways in which *archaeology* and the *digital* articulate and set forth broad programmatic goals for the way this relationship should evolve going forward. For example, Jeremy Huggett called for a more introspective Digital Archaeology, a theory-building approach seeking to understand “the nature of the computational turn in archaeology and its effect on every stage of knowledge creation” (Huggett, 2015a, p. 89). Citing the project to sequence the human genome as an example of a grand challenge that resulted in the creation of critical infrastructure for the fields involved, Huggett called for the identification of an equivalently ambitious project for digital archaeology (Huggett, 2013, p.18). While Huggett did not sketch this out in specific detail, he laid out broad parameters for a grand challenge: it must be fundamental to the discipline, large in scope, revolutionary, inspiring, understandable, measurable, and cooperative (Huggett, 2015a, p. 83). Huggett suggested that digital archaeologists might construct such a grand challenge by developing revolutionary new approaches to data mining, data capture and image processing (Huggett, 2013, pp.21-22). For Huggett, the ultimate purpose of the grand challenge was to “...elevate Digital Archaeology from its status as a technical service” to an established archaeological sub-discipline prominent at the forefront of both method and theory (Huggett, 2015a, p. 94).

Costis Dallas has recently articulated a different “grand challenge” for digital archaeology. Dallas agreed with Huggett that digital archaeology currently tended toward the technical or technocratic. However, Dallas disagreed with Huggett and Llobera’s calls for the establishment of a distinct stronger, more influential sub-discipline of digital archaeology or an archaeological information science. Instead, Dallas argued, “...the “digital” in digital archaeology is destined to become extinct, transparent, and invisible, in the same way as it has been already in such fields as high energy physics or molecular biology” (Dallas, 2015, p. 178). For Dallas, digital archaeology is being absorbed across the breath of the discipline and “[making] a

difference to the broader epistemic and pragmatic contexts of archaeology work” rather than building itself a bigger, stronger silo (Dallas, 2015, p. 178). Citing the increasing, global spread of “pervasive digital infrastructures” to which archaeology must adapt, Dallas articulated his grand challenge as one that would “develop a theory and pragmatic approach towards archaeological curation in the digital continuum, contingent on curation-enabled global digital infrastructures and on contested regimes of archaeological knowledge production and meaning making” (Dallas, 2015, p.200). Dallas’ concept of “pervasive digital infrastructures” meets the seven parameters for a grand challenge laid out by Huggett but is more evenly spread throughout the discipline.

Dallas provided a case study for such infrastructure in the form of a large multiyear, multi-team archaeological project focusing on the Neolithic city of Çatalhöyük, Turkey (Berggren et al., 2015). Influential postprocessual theorist Ian Hodder, who served as one of the excavation leaders, formulated a twelve-point plan to archive a new level of reflexivity in the archaeological workflow, aided by digital technologies. As summarized by Dallas, this plan called for “...site interaction through tours on site; negotiations of priorities between excavators and laboratory staff; breaking down barriers between different kinds of materials and analyses; fast feedback from laboratory analyses to the field; an integrated database; a diary supporting and documenting the process of interpretation; anthropologists looking at archaeological process, visual conventions, and local community impact; a web-based database to enable multivocality; hypertext and hypermedia to break down linear narrative; virtual reality connected to the database and supporting visualization; and teams of diverse nationalities supporting different versions, or “windows”, of Çatalhöyük” (Dallas, 2015, p. 185).

At Çatalhöyük archaeologists therefore employed a multitude of digital technologies not only to document the site, but also to digitally document the archaeological *processes* of recording and interpretation in the field as they took place (Dallas, 2015). The project used state-of-the-art methods to physically record the site in a conventional way, as exemplified by Maurizio Forte’s creation of a virtual 3D model of the entire excavation, an effort that brings the Çatalhöyük project a step closer

towards Reilly's earlier vision for a less destructive "virtual" archaeology (Reilly, 1991; Forte, Dell'Unto, and Haddow, 2013). The digital documentation effort at Çatalhöyük went much further than this, however; the project also sought capture and curate interpretation taking place "at the trowel's edge" through the creation and use of on-site video diaries and the rapid feeding of digital GIS and 3D visualizations and lab results back to excavators as they worked (Berggren et al., 2015). The goal of this rapid digital curation was the creation of a "reflexive loop" that better integrated all of the different types of information being generated at Çatalhöyük and fed them back into the ongoing process of interpretation of excavations as quickly as possible, a process for which project leaders found tablet computers especially well-suited (Berggren et al., 2015, pp. 444-446).

The approach to archaeology at Çatalhöyük thus sought to render the processes of archaeological recording, interpretation and curation inseparable (Dallas, 2015, 186). A final, important component of the project is the digital dissemination of this rich digital record to a wider audience. This currently takes the form of a web repository that hosts digital copies of excavation records, artifact databases, reports, illustrations, photos and videos (Çatalhöyük Research Project, 2017). The project has also produced a "Living Archive", a pilot project that attempts to make the data in the web repository more discoverable through interactive search and visualization functions (Grossman, 2013).

IMPORTANT GAPS IN ARCHAEOLOGY'S DIGITAL REVOLUTION

Perhaps the call for "grand challenges" may serve to solidify digital archaeology as a leading sub-discipline within archaeology as Huggett has suggested. However, Dallas' argument that digital approaches will continue to suffuse throughout the discipline hews closer to what actually appears to be happening in the discipline. Dallas is hardly alone: as Daly and Evans argued a decade before, digital archaeology should not be "a secret knowledge, nor a distinct school of thought, but rather seen simply as archaeology done well, using all of the tools available to aid in better recovering, understanding and presenting the past" (Daly and Evans, 2006, p.9). Digital approaches are increasingly being recognized as a fundamental component of archaeology. A recent

forum published in *American Antiquity* produced no fewer than twenty-five different “grand challenges” for archaeology as a discipline but concluded that “addressing many of these challenges will require both sophisticated modeling and large-scale synthetic research that are only now becoming possible” (Kintigh et al., 2015, p. 19). The authors further concluded that the “greatest payoff” could be gained by exploiting the “explosion” of archaeological data brought about by the curation crisis, though they noted that much of this data remained difficult to access (Kintigh et al., 2015, p. 19). These issues can only be addressed through digital means. Moving in this direction also involves archaeologists becoming more familiar with computer science and other related fields, so that technology may be brought to archaeology by archaeologists with a strong understanding of the approaches they are adapting (Grosman, 2016).

The potential growth of what Dallas calls “pervasive digital infrastructures”, coupled with the ongoing curation crisis and data avalanche within archaeology, have made the discipline’s continued adaptation to digital approaches imperative. While there is no question that archaeology will always remain a study of *things*, the ways in which that inquiry is conducted and understood have been irrevocably altered by the computer revolution. The Çatalhöyük project represents perhaps the most promising attempt to date to identify and move towards the “grand challenge” of integrating digital technology into archaeological theory and practice; nevertheless this “grand challenge” remains a work in progress. Participants at Çatalhöyük admitted that reflexive practice proved much more difficult to achieve in practice than on paper (Berggren et al., 2015; Farid, 2015). Most importantly, the team have not yet fully succeeded in *integrating* and *disseminating* the collected digital information in a way that fosters discovery and engaging visualization for those outside the project team, as the Çatalhöyük Living Archive remains in the prototype stage several years after launch.

From a North American perspective, one branch of archaeology is conspicuous in its near invisibility in the preceding discussion – historical archaeology in all its forms, especially in North America. In reviewing the relevant literature (especially the CAA proceedings), we find that the archaeologists driving the computational revolution in archaeology and discussions of a digital archaeology sub discipline are

overwhelmingly specialists in prehistoric, Neolithic, classical, or medieval archaeology and the bulk of the digital archaeology projects and infrastructures are by and large focused on these types of contexts (Giligny, 2014; Campana, 2016). Archaeological sub disciplines focusing on later periods rarely feature within these discussions. In a recent evaluation of the state of GIS research in historical archaeology, Edward González-Tennant saw American historical archaeology's attitude towards GIS and GIS-based research as lagging well behind the rest of the archaeological discipline, hindered to a great extent by a lingering postprocessual skepticism more reminiscent of the state of digital archaeology in 1990s (González-Tennant, 2016, pp. 41-42).

However, as discussed previously, developments in digital archaeology within the last decade have gone far to address these criticisms, and digital archaeology's absorption into the broader discipline continues apace. The need to better integrate archaeological data with the historical record leaves the archaeology of postindustrial contexts perfectly poised to fill a "post prehistoric" gap in digital archaeology's focus.

CURRENT TRENDS: GIS AND ARCHAEOLOGICAL SPATIAL DATA INFRASTRUCTURES

The foregoing discussion highlights the fact that doing digital archaeology requires robust digital infrastructures, following Dallas' call, that are capable of integrating, storing, curating, and disseminating the wide variety of digital information being generated by archaeologists. Ideally, this infrastructure would be broadly standardized and shared to maximize intra- and interdisciplinary collaboration while maintaining a wide capacity for visualization and analysis; calls for such an infrastructure for archaeology are now over ten years old (Kintigh, 2006; Snow et al., 2006). Despite this, the infrastructure that currently exists in a mature form is either narrowly focused on the storage and curation of data – such as tDAR or ADS - or is the creation of a single research project such as the Çatalhöyük Living Archive (See also McCool, 2014). Creating such an infrastructure is a daunting – and expensive – prospect, and it is unsurprising that discussions of infrastructure represent a tiny proportion of the overall published output of digital archaeology, as captured in the CAA proceedings (Earl et al., 2013; Traviglia, 2014; Giligny, 2015; Campana, 2016). One particularly

relevant ongoing infrastructure project is ARIADNE, an 2013-2017 EU-funded project that integrated 24 archaeological data repositories across Europe into a single, transnational archaeological data infrastructure (Niccolucci and Richards, 2013; Niccolucci, 2015; ARIADNE, 2017). ARIADNE's creators have focused on developing metadata schemas that will render the constituent national archaeology data portals interoperable (Niccolucci and Richards, 2013; for further discussion of the metadata schemas used, see also Doerr, 2003; Doerr and Theodoridou, 2011). Since 2017, the project has evolved into ARIADNEplus, which seeks to expand the infrastructure and achieve higher levels of integrations between constituent datasets and add limited GIS functionality. ARIADNE and ARIADNEplus's primary purpose is to effectively link large existing digital archaeology data infrastructures (such as the ADS in the UK, the DANS in the Netherlands, and ATHENA in Greece), and thus it suffers from most of the same weaknesses of its constituent components (Niccolucci and Richards, 2013; Niccolucci, 2015; ARIADNE, 2017).

Thus, the creation and widespread adoption of a flexible archaeological digital data infrastructure is crucial and in itself represents a "grand challenge". The most active group of archaeologists currently exploring the development of such infrastructure are based in Europe, and several common conclusions emerge from their work (McKeague, Corns and Shaw, 2010; De Roo, Bourgeois, and De Maeyer, 2013; Niccolucci and Richards, 2013; de Kleijn, Manen, Kolen, and Scholten, 2014; Serlorenzi, Jovine, Leoni, De Tommasi, and Varavallo, 2014; De Roo, De Maeyer, and Bourgeois, 2016). These can be summarized as follows: first, current efforts at creating digital infrastructures for archaeologists are fragmentary – especially on the international level, where political considerations begin to serve as substantial barriers to standardization and sharing of data (Niccolucci and Richards, 2013). A greater level of standardization is necessary to make the best use of resources and ensure maximum availability of information. Second, such infrastructures must support at least multidisciplinary, if not interdisciplinary, scholarship and collaboration beyond academia, and especially with the public (de Kleijn, Manen, Kolen, and Scholten, 2014). Current efforts to create data infrastructures have focused on facilitating scholarship, but ultimately such infrastructures should make

data discovery, visualization and participation available to the public as well. Lastly, and perhaps most importantly, such infrastructures should take the form of GIS-based *spatial* data infrastructures (SDIs) (McKeague, Corns and Shaw, 2010; De Roo, De Maeyer, and Bourgeois, 2016). Space has been recognized as a powerful integrating and unifying concept both within archaeology and elsewhere in the social sciences and humanities (Goodchild and Janelle, 2004; Niccolucci and Richards, 2013), and using a space as a fundamental organizing principle is likely the most effective way to address issues of language, parallel classification systems, and other potential obstacles to widespread adoption and use of a common digital data infrastructure. These issues represent some of the most significant hurdles in the grand challenge of developing the “pervasive digital infrastructures” envisioned by Dallas (Dallas, 2015 p. 176).

“SLOW ARCHAEOLOGY”: PRESERVING THE CRAFT OF THE DISCIPLINE

The initial postprocessual reaction to computer-aided archaeology was merely the first in an ongoing critique of the growth of digital approaches within the discipline that continues to this day. Bill Caraher (2016; 2019) used the term “slow archaeology” as a counterpoint to what he identified as the growing application of digital archaeology in the name of efficiency, particularly with respect to data collection in the field. Situating archaeology, and especially cultural resource management (CRM) archaeology, within the context of industrial capitalism, Caraher cautions that digital data collection can “fragment” of the experience of doing archaeology in much the same way that industrial production fragments tasks in the name of efficiency (Caraher, 2016 p. 428). This fragmentation obscures the value of the craft and the deliberate human experience of archaeological practice. Digital data collection and analysis lends itself to the systematic approaches championed by processual archaeology, which always carry the danger of “black boxing” the process of archaeological interpretation (Caraher, 2016 p. 428), and moves the primary locus of archaeological interpretation from the field to the office (Caraher, 2016 p. 436). Caraher warns that the uncritical adoption of more “efficient” digital approaches may be changing the nature of archaeological practice; as we place less emphasis on field diaries and notes, and more on remote-sensing data,

GPS-based survey data, and the like, we risk deskilling the practice of archaeology as we move away from individual on-the-spot interpretation (Caraher 2016; 2019).

Caraher's discussion of the need for a "slow archaeology" refocused on the personal experience of the archaeologist was primarily concerned with the dangers of the adoption of digital data recording and analysis approaches in the name of efficiency. The point is well made, though the digitally-augmented "reflexive loop" developed by archaeologists at Çatalhöyük demonstrates that digital approaches also hold the potential to support the craft of archaeological field interpretation field rather than obscure it (Grossman, 2013; Dallas, 2015).

In considering Caraher's critique in the context of Dallas' grand challenge, I also draw a distinction between the issues surrounding work in the field and the challenges of working with and caring for datasets that have already been excavated. With the number of orphan collections continually growing, it is clear that archaeology needs to pay more attention to what happens to our data after the fieldwork ends. Field notes, drawings, and other data, still the primary record of the archaeologist's craft in many cases, are useless if they languish uncared for in deep storage or – still worse – are damaged or destroyed through neglect. The same can be said for the artifact assemblages themselves. In the case of the records, the potential demonstrated by previously mentioned efforts to develop transnational data infrastructures such as ARIADNE suggest that, while progress is being made, the discipline has plenty of room for improvement in curating the records of our craft and making them sufficiently accessible. Finally, addressing the grand challenge of large-scale digital infrastructures forces us to consider the nature of archaeological practice; if we are to digitally augment the practice of archaeology, it is crucial to start from a solid understanding of that practice. Caraher's critique is useful in that it encourages us to continue to consider the ways in which the use of digital approaches may alter archaeological practice (Hiuvila and Huggett, 2018).

HISTORICAL GIS, GISCIENCE AND HISTORICAL SPATIAL DATA INFRASTRUCTURES: COMPLEMENTARY DEVELOPMENTS AND LESSONS FOR ARCHAEOLOGY

In meeting the challenges inherent in building archaeological digital data infrastructures, historical/urban/industrial archaeology sub disciplines are especially relevant because of their proximity to historically-focused subdisciplines elsewhere in the social sciences and humanities that have already developed digital infrastructures that may serve as foundations for the development of a next-generation of archaeological digital data infrastructure. As with archaeology, scholars using computer-based methods within the social sciences and humanities also underwent a postmodern critique and responded with new ways of applying digital technologies such as GIS to studies of the past within (and across) their respective disciplines. I will explore the ways these approaches to digital scholarship in general, and applications of GIS in particular, can ultimately support new ways of the archaeology of postindustrial spaces.

Within the social sciences and humanities we find several disciplines that take an interest in the study of the past, as exemplified by the wide range of scholarship published in the journals such as *Social Science History*. Among these we find human geographers, historians, demographers, sociologists, and others who, like archaeology, take a spatial approach to understanding the past. Within this context scholars have developed innovative digital approaches to the study of the past, some of which also serve as promising tools of public engagement. The experience and innovations of geographers and historians working within these specializations bear close examination by archaeologists studying postindustrial places, as they provide a “missing link” between the latest digital archaeology approaches, biased as they are towards pre-historical contexts, and the calls put forth by urban and contemporary archaeology.

THE QUANTITATIVE REVOLUTION

Archaeology’s early experiments with computers in the 1950s took place contemporaneously with parallel developments in the social sciences and humanities such as human geography (where the phenomenon became known as the “quantitative revolution”) and history (Burton, 1963; Anderson, 2007). Like archaeology, this was a process of borrowing and adapting methods from the natural sciences and the development of more “scientific”, quantitative analysis-based theory and practice in

geography; GIS, initially developed for the earth sciences, was especially attractive to geographers as a tool for spatial analysis. (Burton, 1963; Dennis, 1991; Barnes, 2000; Schuurman, 2004; Anderson, 2007; Heffernan, 2009). The sub discipline of human geography in particular (which includes historical geography), in common with processual archaeology, saw the quantitative revolution as an opportunity to use computer-based models or statistical analyses to develop more generalized models of human behavior, and embraced GIS when the arrival personal computers made it affordable (Mitchell, 1987; Dennis, 1991, Baker 2003). History likewise saw the emergence of a series of “new” histories that utilized “quantitative reconstructions” derived from statistical data to support explanations of historical processes (Thernstrom, 1964; Katz, 1975; Hershberg, 1973; Hershberg and Burstein, 1976; Cross, 1977, p. 119; Conzen, 1983; Monkkonen, 1984; Anderson 2007). This was especially popular among urban historians with access to large bodies of tabular records that were relatively easy to subject to statistical analysis with computers (Zunz, 1982; Conzen, 1983; Mohl, 1997; Anderson, 2007).

POSTMODERN REACTIONS: THE SPATIAL TURN, THE CULTURAL TURN, AND CRITICAL GIS

The postmodern reaction to quantitative scholarship within these disciplines paralleled the postprocessual critique in archeology in many ways. Taking place at about the same period through the 1980s and 1990s, this critical shift, which became known as the “cultural turn”, had a substantial impact on history and historical geography scholarship that had adopted quantitative methods (Dennis, 1991; Anderson, 2007). Within quantitative history, critiques of the limitations of such methods led to some early proponents subsequently renouncing quantitative methods; while quantitative history did not disappear it never achieved general adoption within the field, and by the 1990s the situation remained one of “uneasy truce” (Anderson, 2007, p. 257). Since the turn of the 21st century, classical statistics-focused quantitative history has in fact (apart from economic history) experienced a decline (Hudson and Ishizu, 2017).

Within human geography, postmodern critiques were characterized by the adoption of more reflexive theories and epistemologies that recognized the “contingency

of knowledge claims” and the influence of dynamic, contested cultural perspectives on the study of geography (Barnett, 1998, p. 380; Castree, Kitchin, and Rogers, 2013). Historical geographers began to engage with critical and social theories addressing themes such as identity, the limitations of capitalism, gender, race, and imperialism/colonialism (Harvey, 1982; Black, 1989; Jackson, 1989; Bondi, 1990; McDowell, 1992; Crush, 1994; Cook, Crouch, Naylor, and Ryan, 2000; Kobayashi, 2000; Berry and Henderson, 2002; Withers, 2009; Castree, Kitchin, and Rogers, 2013). GIS became, by virtue of its growing popularity amongst geographers in the 1990s, a high-profile target for many of the most pointed critiques by postmodern scholars. The so-called “critical GIS” debates of the 1990s saw postmodern scholars accusing geographers using GIS of “the very worst sort of positivism, a most naïve empiricism”, ignoring contextual knowledge, adopting assumptions of being value-neutral, objective, and of achieving subject-object separation (Taylor, 1990, p.212; Smith, 1992; Lake, 1993; Sheppard, 1995; Pickles, 1995; Pickles, 1997; Schuurman, 2000). This tense and passionate debate bore fruit in the shape of a new interdisciplinary subfield called GIScience that sought to address “generic issues of spatial data” raised by postmodern scholars (Wright, Goodchild, and Proctor, 1997, p.348), as well as the implications of the social construction of GIS (Goodchild, 1992; Wright, Goodchild, and Proctor, 1997; Schuurman, 2000, p. 577; Elwood 2010, p. 46; Gregory & Geddes, 2014, p. x; Goodchild, 2015, p. 3).

Another outcome of the cultural turn was the increasing distinction drawn between “space” as an absolute physical dimension and “place”, a socially constructed phenomenon that coupled physical space with much more complex, contested and culturally embedded values (Withers, 2009). Concepts of “place” were hardly new to the social sciences and humanities, but postmodern scholarship saw understanding the influence of space as crucial to understanding “human behavior and cultural development”, to the extent that scholars began referring to a “spatial turn” within the social sciences and humanities (Bodenhamer, Corrigan, and Harris, 2010).

QUALITATIVE GIS, HISTORICAL GIS, AND HISTORICAL SPATIAL DATA INFRASTRUCTURES

In the wake of the cultural and spatial turns, GIS-based scholarship within the social sciences and humanities has focused on developing more effective ways to conduct qualitative research using GIS. As with archaeology, much of this effort has been turned towards exploiting new (often spatially-aware) visualization capabilities of digital technologies and the participatory potential of Web 2.0. One obvious and important, yet often overlooked, means to undertake digital scholarship in a postmodern environment is through the exploitation of metadata as a means to qualitatively contextualize GIS datasets. Nadine Schuurman has proposed the implementation of “ontology-based metadata” wherein information about the “sociological, political, and technical influences that bear on data” may be recorded (Schuurman, 2009, p.48). Ontology-based metadata includes not only information about the culture from which it was collected, but also the rationale, methodologies, and taxonomic or measurement standards of the data collectors. While rigorous use of metadata has always been considered best practice within GIS, Schuurman makes the point that, for *qualitative* digital data to be useful, it is critical that the ontological origins of that data be known and retained in its digital form (Schuurman, 2009). The need to balance richness and standardization within metadata schemas has been noted by the designers of archaeological data infrastructures (Niccolucci and Richards, 2013; De Kleijn, van Manen, Kolen, and Scholten, 2014), and Schuurman’s argument is an important one for such archaeologists to keep in mind.

Another thread of development towards a “qualitative GIS” are mixed methods approaches that seek to maintain the qualitative nature of the data and research processes while taking advantage of the affordances of digital technology (Knigge and Cope, 2006; Knigge and Cope, 2009; Jung and Elwood, 2010). LaDona Knigge and Meghan Cope’s “Grounded visualization” serves as one notable example of this; they combined “grounded theory” – the collection, coding and iterative comparing of qualitative data – with GIS-based visualization techniques as a method for better understanding contested urban spaces (Knigge and Cope, 2006). Grounded visualization uses GIS as a way to spatially contextualize large qualitatively coded digital data sets; the analysis itself is left to the human researcher, who looks for patterns within a dataset that can be viewed from

numerous different perspectives (Knigge and Cope, 2006; Knigge and Cope, 2009; see also Jung and Ellwood, 2010). While others have attempted similar approaches without GIS or without the use of computers at all (c.f. Knowles, Westerveld and Strom, 2015), the use of GIS as a visualization tool permits visualization from perspectives and at scales impossible to achieve without computers (Knigge and Cope, 2006; Knigge and Cope, 2009). While this research has largely been developed using contemporary contexts as case studies, we can see in the iterative, reflexive nature of these qualitative GIS approaches much similarity with the use of digital methods by archaeologists at Çatalhöyük; indeed, the former serves as a useful counterpart to the latter for the undertaking of archaeological research *after* the fieldwork phase has been completed. Like historical geographers, archaeologists must also account for the passage of time as well as space in their research however, and for that element we must look to the lessons learned during the development of historical GIS. HGIS, a “collision” of geography and history (Bailey and Schick, 2009, p. 291), evolved specifically as a means to study the past spatially and from previously unexplored perspectives (Knowles, 2000; Gregory, Kemp, and Mostern, 2001; Holdsworth, 2003; Gregory and Ell, 2007; Gregory, DeBats, and Lafreniere, 2018). Initially, historical geographers and historians developed HGIS as a way to create large, national scale spatial databases that could contextualize digitized gazetteers and historical tabular data such as censuses and economic records within administrative boundaries across time (De Moor and Wiedmeann, 2001; Gregory et al., 2002; Fitch and Ruggles, 2003; McMaster and Noble, 2005; Kim, 2005; Merzlyakova, 2005; Knowles 2005; Gregory and Healey, 2007, Gregory and Ell, 2007). HGIS, as a spatial tool capable of working with historical big data at a wide variety of scales, is therefore uniquely suited to the needs of historical and urban archaeologists who incorporate large, densely layered historical datasets into their work (Dickens, 1982; Cantwell, & Wall, 2001; Mayne and Murray 2001; Rothschild and Wall, 2014).

HGIS emerged at the end of the 1990s, after the critical GIS debates had led to the creation of GIScience and its more critically reflexive use of GIS; HGIS scholars thus had to overcome several major issues raised during those debates. Chief among these were the potential for aggregation errors such as the modifiable areal unit problem

(MAUP), in which the specific scale or administrative boundaries selected for use in an HGIS skews analytical results (Openshaw, 1984; Kwan, 2012); and the ecological fallacy, where spatially aggregated data at a gross scale is applied to the level of the individual (Goss, 1995, p. 134; Gregory and Ell, 2007). Another issue particularly impacting HGIS was the difficulty of adapting GIS to handle time, an issue that archaeologists currently using GIS are also keenly aware of (Ebert 2004; Gregory and Ell, 2007, p. 119; Goodchild, 2013).

In responding to these challenges, HGIS scholars have developed new approaches that hold great promise for the application of HGIS to archaeology. Some of these are the result of narrow technical solutions or the incorporation of higher-quality datasets. For example, they have addressed the MAUP through both greater methodological rigor in identifying and integrating boundary data (Gregory and Southall, 2002), and have reduced the risk of ecological fallacy through the use of increasingly fine-grained datasets (Logan, Jindrich, Shin, and Zhang, 2011; Lafreniere and Gilliland, 2014). The ability to scan historical maps at high resolution and georeference them for use within an HGIS has further served to provide context and detail at scales impossible to replicate with “analog” forms of data (Rumsey and Williams, 2002; Churchill and Hiller, 2008). Textual sources have long bedeviled attempts at incorporation into GIS, but recent developments in the use of corpus analysis suggest that HGIS may soon regularly be able to make use of this critical resource as well (Gregory, Cooper, Hardie, and Rayson, 2015; Rayson et al., 2017). HGIS scholars have also embraced the growing ability of GIS to represent landscapes in 3D (Rumsey and Williams, 2002, pp.3-4; Gregory and Ell, 2007; Lafreniere and Gilliland, 2014; Arnold and Lafreniere, 2018). HGIS researchers thus have a great deal of experience in linking large bodies of data across space and time through spatial analysis and visualization, and this experience could be drawn upon to help address the need for archaeologists to make better use of the analytical/visual potential of GIS, as highlighted by Early-Spadoni (2017), for example.

The desire to maximize the use of different types of historical sources within a HGIS has recently led to the concept of the historical spatial data infrastructure (HSDI),

an HGIS that is meant to serve as a very broad, flexible and extensible space-time research tool (Lafreniere, 2014; Lafreniere and Gilliland, 2014; Lafreniere et al., 2019; HISDI-MAD, 2017). Where previous HGIS-based approaches focused on placing demographic or economic data within relatively gross (though increasingly fine-grained) boundaries such as census tracts, the HSDI establishes “stages” focusing on the built and social environments to support integral qualitative *and* quantitative analytical and public-participatory capabilities previously only attempted with GIS on an *ad hoc* basis (Lafreniere and Gilliland, 2014; Lafreniere, 2017 forthcoming); these significantly expand the value of GIS as a tool of research and public outreach. With the ability to store, visualize, analyze and disseminate data within a patio-temporal digital environment, the HSDI represents the best tool yet developed to apply spatial thinking to the study of historical processes while taking advantage of historical big data (Lafreniere et al., 2019).

As discussed previously, prehistoric and classical archaeologists have also developed ways to visualize and manage archaeological data, and have begun to design archaeological SDIs, but these efforts remain focused towards providing large-scale access to archaeological data rather than developing SDIs capable of supporting analysis or public dissemination. Moreover, these developments have largely bypassed historical/urban/industrial archaeology, with its need for mixing archaeological and historical sources to support qualitative research (González-Tennant, 2016). For these latter especially, the HSDI approach represents a potentially transformative way to address the challenges of archaeology in postindustrial in urban places and, by extension, contributes to broader understandings of postindustrial places.

TOWARDS A DIGITAL, SPATIAL INFRASTRUCTURE FOR ARCHAEOLOGY IN POSTINDUSTRIAL URBAN SPACES

Accelerating development worldwide, coupled with the increasing global adoption of digital data collection methods, has resulted in archaeologists having to attempt to properly curate ever-growing bodies of archaeological data in both physical and digital form. How do we properly care for all of this data while also keeping it – and

the archaeological process – transparent and accessible? By increasing the scale of archaeology to that of the industrial, we exacerbate these issues unless we adopt new means to address them.

Developments emerging out of the ongoing digital revolution in archaeology have the potential to contribute to addressing all of these calls and challenges to some degree; despite this, and though the awareness and adoption of computer-based methods is accelerating within archaeology, the spread of digital approaches within the discipline has been uneven. Digital data collection methods have become very popular, even indispensable, within most sub disciplines of archaeology; the use of sophisticated digital *analysis* tools remains a more specialized branch of archaeology, however (Grosman, 2016). Perhaps most importantly of all, the use of digital tools for the purpose of sharing archaeological knowledge more freely outside the discipline has yet to be fully exploited (Morgan and Eve, 2012). Within this context, we find that the penetration of new digital approaches – especially new uses of GIS – into historical archaeology in particular lags behind that of the rest of the discipline, in part due to lingering postprocessual suspicions of computer-aided archaeology approaches (González-Tennant, 2016).

Archaeology concerns itself with the entanglement between things and people (Hodder, 2011). Archaeologists study the past in fundamentally material and spatial ways (Aldenderfer, 1996; Edgeworth, 2012; Huggett, 2015a). Elsewhere within the social sciences and humanities, geographers and historians who engage in spatial thinking about the past have developed various new digital approaches to this research, especially through the use of GIS. The development of historical GIS and HSDIs using historical big data have enabled scholars in the social sciences and humanities to study the past over large spatial and temporal scales, afford qualitative research, and while retaining a high level of detail (Gregory and Ell, 2007; Cope and Ellwood, 2009; Lafreniere and Gilliland 2015; Lafreniere et al., 2019; Lafreniere and Gilliland, 2018). HGISs and HSDIs approaches, when informed by Critical GIS and GIScience scholarship stressing transparency, reflexivity, and the mixing of qualitative and quantitative approaches (Cope and Ellwood, 2009; Gregory and Geddes, 2014) can help

address the types of postmodern critiques historical archaeologists often stills see as a barrier to an expanded archaeological use of GIS (González-Tennant, 2016). Moreover, scholars have already constructed HSDIs within postindustrial landscapes (Lafreniere and Gilliland 2015; Lafreniere et al., 2019). With these developments in mind, **how can spatial digital infrastructures using big data approaches, specifically the HSDI, enhance the archaeological study of postindustrial urban landscapes?**

In addressing this question, I am conscious of calls for the formulation of “grand challenges” directed towards “generating major changes, expanding boundaries, intensifying research activities, and mobilizing resources” in the implementation of digital approaches to archaeology (Huggett, 2015b, p.81). Though much of this discussion takes place within the digital archaeology subfield, it is increasingly likely that the growing absorption of digital approaches will take place across the breadth of the discipline (Dallas, 2015). Efforts to design digital (and in some cases spatial) data infrastructures for the curation and sharing of archaeological knowledge represent one “grand challenge” for digital archaeology, but these remain focused primarily on research needs and do not yet support visualization, analysis, and reciprocal interaction with the public. HGIS and HSDIs can support these features (Lafreniere et al., 2019), but such GIS approaches remains underutilized within archaeological circles, especially in North American historical archaeology (González-Tennant, 2016). Taken together, Huggett and Dallas’ calls for the formulation for digital “grand challenges” for archaeology and González-Tennant’s call for the expanded use of GIS in historical archaeology expose a need for the development of new ways of doing archaeology that expand the scale of historical archaeological inquiry and take advantage of the big data capabilities of digital technologies, especially GIS.

This dissertation aims to answer that need by demonstrating that the adoption of an HSDI approach to the archaeology of postindustrial places better equips us to meet the needs of archaeology within this context, and makes a contribution to Dallas’ (2015 p. 176) call for “pervasive digital infrastructures” as a grand challenge for the discipline . In Dallas’s vision, archaeologists couple the reflexive recording of archaeological knowledge production with globally-accessible digital data infrastructures; I argue that

any such digital data infrastructure must also be *spatial* and incorporate *historical* big data in the form of an HSDI. Archaeology is the most materially oriented of the social sciences (Edgeworth, 2012; Huggett, 2015). Archaeologists studying more recent periods must nevertheless make full use of the historical sources available to them during the research design process. Moreover, the digital curation and sharing of archaeological knowledge within an HSDI will help to address the “curation crisis” and data avalanche” by storing and permitting meaningful access to this data, both for researchers and the public. HSDIs show great potential for providing archaeologists working in postindustrial places with a means to curate and manipulate historical data from the individual spatial scale to the industrial or urban scale, as well as across time scales ranging from seconds to centuries. HSDIs can help us iteratively contextualize these longitudinal datasets, both qualitative and quantitative, with historical data, material culture and other forms of archaeological knowledge through the use of both flexible visualization and various forms of spatial analysis. This dissertation argues for the use of HSDIs as the basis of spatial data infrastructures for transdisciplinary research in postindustrial contexts, as a platform for linking research in the academy to urban decision-makers, and for more meaningful and effective engagement with broader society (Figure 1).

FIGURE 1: The HSDI as a common platform for understanding the postindustrial city.

In conceptualizing the application of digital, spatial approaches to archaeology, my overarching theoretical approach follows the “new pragmatism” as it is applied to archaeology (Pruecel and Mrozowski 2010). Given the contested nature of the past (Meskell, 2015), and the role of this contested past in the issues surrounding postindustrial “legacy” cities today (High, MacKinnon, and Perchard, 2017; Mallach, 2018), it is crucial to ground archaeological research in the present (Mrozowski, 2014). We must position our research so that it represents less the product of an esoteric, siloed specialization and instead informs real-world social discourse concerning pressing issues in the contemporary world. We should seek out and develop the practical applications for archaeology that make a positive contribution towards a more equitable and sustainable future. Within the context of this dissertation, the ultimate goal of the development and adoption of digital infrastructures by archaeologists and their collaborators, and the meeting of Dallas’ grand challenges, is that they support positive interventions in society. In the case of the HSDI, the broad ambitions of this research are

twofold. First, to actually achieve true interdisciplinarity in our study of the past (a common but still elusive target) through more sophisticated sharing and manipulation of a wide variety of digitized, spatialized big data. Second, and more importantly, to demonstrate that infrastructures like the HSDI, and the archaeological knowledge contained within it, can be relevant tools that people outside the academy can actually use to address ongoing issues in postindustrial places.

The new pragmatism also applies to how I situate HSDIs in the debates over digital archaeology's role within the discipline. The HSDI is intended to contextualize the modern postindustrial landscape within its past iterations, and to afford insight into how past phenomena acted as preconditions for the present. By iteratively returning to the data, constantly zooming in and out between different scales of time and space, juxtaposing qualitative and quantitative sources, and collaborating with community in the design and use of the infrastructures, my application of HSDIs to archaeology within this dissertation represents a “slow” approach to digital archaeology. This focuses on using computing power to better contextualize archaeological research and afford new perspectives rather than increasing efficiency at the expense of “[uncritically] occluding technological processes in archaeological practice” (Caraher, 2016, p. 437). I argue that a “slow” approach to digital archaeology using HSDIs represents what Gary Lock called a “pragmatic middle ground” for digital archaeology between the “useful extremes” of processual positivism and postprocessual skepticism (Lock, 2003, p.4).

STRUCTURE OF THE DISSERTATION

This dissertation follows an integrated article format. Following this introduction, I present three chapters (1-3) I have prepared for publication in peer-reviewed academic journals. I follow this with a conclusion chapter incorporating a reflection on results achieved thus far and indicating future research directions.

The first paper (Chapter 1), titled “Historical Spatial Data Infrastructures for Archaeology: Towards a Spatio-Temporal Big Data Approach to Studying the

Postindustrial City,” is currently in press with *Historical Archaeology*. This chapter introduces the HSDI as an innovative approach for expanding the scale of historical archaeology research. Answering González-Tennant’s (2016) call for better applications of GIS within this subdiscipline, I demonstrate the ways in which using HSDIs helps reconfigure GIS as a process rather than simply a tool within archaeology by expanding the geographic and temporal scales of historical archaeological research as well as better embracing big data more generally.

The second paper (Chapter 2), titled “Understanding Cumulative Hazards in a Rustbelt City: Integrating GIS, Archaeology, and Spatial History” has been submitted to the journal *Urban Science*. This chapter demonstrates how the HSDI can be used to longitudinally model industrial activity and industrial hazards in a postindustrial city, demonstrating the spatial analytical capability of the HSDI at small and large (industrial) scales. I argue that this approach may be applied to improve collaboration between academic researchers, professionals, and urban decision-makers.

The third paper (Chapter 3), titled “Heritage Making through Community Archaeology and the Spatial Humanities,” is currently in press with *The Journal of Community Archaeology and Heritage*, critically examines the relationship between heritage experts and communities within postindustrial landscapes and demonstrates how an HSDI-based public engagement program can help address ongoing challenges to supporting the grassroots promotion and protection of heritage.

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**HISTORICAL SPATIAL DATA INFRASTRUCTURES FOR ARCHAEOLOGY:
TOWARDS A SPATIO-TEMPORAL BIG DATA APPROACH TO STUDYING
THE POSTINDUSTRIAL CITY**

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ABSTRACT

While the use of GIS has become commonplace within the discipline of archaeology, the potential of a big-data approach to GIS is yet to be fully exploited within historical archaeology. Archaeologists inspired by developments in the social sciences and humanities have recently called for new ways of conceptualizing GIS as a process that is more theoretically satisfying and methodologically effective in its applications to archaeology. We respond to these calls by proposing a new approach for GIS in historical archaeology, a historical spatial data infrastructure (HSDI). We outline the progression from historical GIS to the construction of an HSDI and present a series of case studies that demonstrate how using a spatio-temporal big data-based approach expands our scale of archaeological inquiry to studying the postindustrial city.

KEYWORDS

Historical GIS, Postindustrial, Big Data, Urban

INTRODUCTION

Geographic Information Systems (GIS) leads something of a double life within the discipline of archaeology. Archaeologists were early adopters of GIS technology (Allen et al. 1990; Aldenderfer and Maschner 1996; Kvamme 1999), and GIS has since established itself as the most commonly used tool for the gathering, management, and integration of spatial data into archaeological research in both cultural resource management and academic archaeology (Lock and Pouncett 2017). Despite this broad embrace by the discipline, GIS continues to be a source of theoretical unease. GIS, with its quantitative roots, is sometimes criticized for a tendency towards atheoretical application (Howey and Bouwer Burg 2017b), and its “point and click” ease of use (Kvamme 1999: 185), may seem a persistent incongruity in the context of the more self-reflective theoretical environment archaeology inhabits today (Lock and Pouncett 2017). Archaeologists thus seem faced with an unappetizing choice “...either to perceive GIS-related practices in archaeology as atheoretical and having self-evident benefits...or to dismiss them for the sake of postpositivist counter-modernist research” (Hacıgüzeller 2012:246). This state of affairs has not prevented the growth of GIS in archaeology, or of computational archaeology approaches in general, but it has led to a chronic “anxiety discourse” among computational archaeology practitioners who remain to some extent unsure of their theoretical ground (Huggett 2013:15). Decades after its initial appearance, computational approaches to archaeology, including GIS, are still spoken of broadly as an emerging field (Huggett 2013).

Historical archaeologists have not as yet contributed much to these discussions. Previous general reviews of archaeological applications of GIS (Aldenderfer 1998; Kvamme 1999; Ebert 2004; McCoy and Ladefoged 2009) or standard texts on the use of GIS or spatial technologies within archaeology (Allen et al. 1990; Aldenderfer and Maschner 1996; Lock 2000; Conolly and Lake 2006) have generally featured few, if any, discussions or case studies that foreground historical archaeology. In a much-needed exception to this status quo, González-Tennant (2016) recently reviewed the use of GIS in historical archaeology and remarked that “The use of GIS is now a core aspect of historical archaeology, but work remains to fully realize the technology’s potential for

the discipline.” (González-Tennant 2016:41); geospatial analysis (such as predictive modeling, viewshed analysis, least-cost path analysis) in historical archaeology, though growing, is still less prevalent than in other archaeological subdisciplines (González-Tennant 2016). This relative lack of experience with geospatial analysis, coupled with the theoretical misgivings mentioned previously, may make historical archaeologists especially prone to seeing GIS as merely a ‘tool’ for data management, and as a result less engaged with broader discussions of the role of GIS in archaeology. To truly take advantage of GIS, historical archaeology must begin to see GIS as more than simply a *tool*, but as a *process*, with appropriate theoretical and methodological foundations (González-Tennant 2016; Howey and Brouwer Burg (2017a:2). Herein we present a methodological approach to GIS for historical archaeological research that facilitates this evolution from *tool* towards *process*. Using the postindustrial city as our laboratory, we outline the creation of a historical spatial data infrastructure that harnesses the spatio-temporal and big data analytical capabilities of GIS.

INTERSECTIONS OF ARCHAEOLOGY AND SOCIAL SCIENCE GIS

Archaeology has always been an inveterate borrower of theory (Lucas 2015); with respect to the use of GIS, archaeologists can point towards several promising theoretical developments in the social sciences and humanities that expand the use of GIS as a means to study the past and its influence on the present. The explosion in the use of GIS in geography by the early 1990s led to a tense debate between GIS practitioners and postmodern theorists within the social sciences over two decades ago (Schoorman 2000), resulting in the rise of the subdiscipline of ‘critical GIS’. Critical GIS scholars argue that, in order for GIS-based research to mitigate the issues inherent in a technology with positivist and deterministic origins, GIS-based research in the social sciences must diversify the types of data being worked with, how it is collected, and how it is interpreted (O’Sullivan 2006; Schoorman 2017). To meet these critiques, scholars have adopted more democratic or inclusive approaches to GIS-based research including Participatory GIS (PGIS), Public Participatory GIS (PPGIS), and Volunteered Geographic Information (VGI) (Brown and Kytta 2014; Craig et al. 2003; Goodchild

2007). The result of this process has been the emergence of a GIScience that focused on the conceptualization of GIS as a critical, reflexive process of digital, spatial inquiry rather than simply the use of software tools (Goodchild 1992; Goodchild and Janelle 2004; Egenhofer et al. 2016). Archaeological research has of course always involved spatial thinking (Lock and Pouncett 2017), and GIScience serves as a useful theoretical foundation for archaeologists dealing with challenges unique to working with spatial data in a GIS.

Spatial history and the spatial humanities also represent useful sources of inspiration for archaeologists using GIS. The recent ‘spatial turn’ in the humanities, which sought to foreground concepts of place in humanities research, brought GIS to the attention of humanists. Spatial history involves collaborative historical research that makes use of digital approaches and visualizations to develop unique historical narratives and counter-narratives (Knowles and Hillier 2008; Gregory et al. 2018b, Olson and Thornton 2011). Following on from this, the spatial humanities (Bodenhamer et al. 2010; Gregory and Geddes 2014; Bodenhamer et al. 2015) have begun to develop a theoretical framework for applying GIS and related spatial technologies to mixed methods inquiries. Major themes in spatial humanities research that should appeal to historical archaeologists using GIS include: finding ways to incorporate texts and other non-traditional data sources within GIS (Lafreniere and Gilliland 2015; Donaldson and Gregory 2016); reducing reliance on desktop GIS in favor of the use of more widely accessible Web-based GIS or GIS-like software such as Social Explorer (<http://www.socialexplorer.com>); further developing the spatio-temporal capabilities of GIS to permit more sophisticated explorations of space-time (Gregory et al. 2018b); finding more effective ways to represent the multiply constituted or contingent nature of place (Bodenhamer et al. 2010).

A popular recent development within the spatial humanities has been the emergence of the concept of ‘deep maps’. Bodenhamer et al. (2015) theorize that deep maps embrace multiple forms of media, provide more democratic access to data, better accommodate imprecision and subjectivity of data, and foster the presence of multiple voices and interpretations. While deep maps seek to move beyond the positivist or

deterministic constraints of GIS as a ‘tool’, they do still often incorporate GIS in some form as a digital spatial framework within which such maps may be constructed (Lafreniere et al. 2019; Ridge et al. 2013; Scarlett et. al 2018). The ultimate goal of deep mapping is the creation of digital contexts operating at phenomenological scales (Lock 2010) that people may use to create spatial narratives, using the power of information technology to combine complex, varied, “resplendently untidy” sets of spatialized, digital information into meaningful representations of place (Harris et al. 2015:224).

Up to this point archaeology has made little more than a token contribution GIScience, spatial history, or spatial humanities literature, and with very few exceptions, such as Hays et al. (2018), most archaeologists remain largely unaware of these fields (Earley-Spadoni 2017). This critique cuts both ways; while historical GIS in particular purports to be an interdisciplinary approach to studying the past through the use of geospatial approaches, its practitioners rarely engaged with archaeologists using GIS (Allen et al. 1990; Kvamme 1995; Kvamme 1999; Lock 2000; Lock 2003; Conolly and Lake 2006) who developed their own theoretical and methodological approaches over the course several decades. It is here that historical archaeology is perhaps best placed to take a leading role in meeting recent calls for the wider field of archaeology to be more closely engaged with these new approaches to GIS-based research (González-Tennant 2016; Howey and Bouwer Burg 2017b). Historical archaeology’s use of the historical record as a fundamental component of research is an approach shared with other disciplines in the social sciences and humanities who study the past, though historical archaeology contributes its own unique perspective to historical research (Orser 2017).

Archaeologists need new methodological approaches that apply GIScience to archaeological research and allow us to more usefully represent space and place and how they change over time, bringing us closer to effective mixed qualitative/quantitative GIS research, and perhaps ultimately to deep mapping. We require a digital framework or infrastructure that can support new types of data, better access to that data (both for collaborative research and the public participation), more effective longitudinal representation and inquiry, and useful juxtapositions of multiple, often conflicting representations of place. In proposing such an infrastructure, we look to the social

sciences and recent developments in historical GIS (HGIS) for our methodological foundation. Researchers in the fields of geography, sociology, history, and historical demography (among others) have developed HGIS as an approach to modelling past historical environments, and HGIS holds great promise for historical archaeologists as an innovative means for modeling past environments. The historical record can, in some ways, support more granular models of past environments that complement the detailed environmental data used by prehistoric and classical archaeologists. Our approach to GIS will allow historical archaeologists to more fully exploit this potential.

GIS, CRISES OF REPRESENTATION, AND CHALLENGES OF SCALE

An ongoing theoretical constraint to better representing past environments using GIS has been the so-called “crisis of representation” brought about by the inherent differences between space and place, and seemingly insurmountable difficulties in adapting Cartesian space to human understandings of distance, direction, position (Lock 2010; Lock and Pouncett 2017:130). This can be seen, in part, as problems with our notions of scale and landscape, where GIS struggles to transition from recoding “analytical scale” to “phenomenological scale” (Lock and Pouncett 2017:131). Any proposed spatial infrastructure must be able to handle the challenges of *scale* in several senses before this transition can be approached:

Geographic Scale

- An important aspect of archaeology is the linkage between every day, micro scale activities and the macro scale phenomena that characterize societies. A spatial infrastructure for archaeology must be able to encompass information about both of these extremes of geographic scale and allow researchers to easily move across varied geographic scales.

Temporal Scale

- Handling time within GIS is challenging (Goodchild 2013) and representing change over time is an even greater challenge. Archaeologists need the ability to represent change over time in discernable, accessible ways. It is crucial to not only to studying dynamic phenomena in the past, but also to link phenomena to the present.

The Scale of Big Data

- With the quantity of digital data being generated in archaeology growing exponentially (Petrovic et al. 2011), archaeology (and the social sciences generally) are entering the era of big data (McCoy 2017; Thatcher et al. 2018). Working with big data carries with it a multitude of challenges including the need for greater computational expertise, more transparency in our digital data collection and analysis, and learn to work “ultra-longitudinally” across previously separated time periods (Bevan 2015:1481). Within archaeology, this includes the need to be able to handle, analyze, and manipulate increasing bodies of digitized historical data, whether that be cartography, records, texts, or visual media.

Addressing such issues of scale is a crucial component of the process of developing a more flexible and robust spatio-temporal, multiscale spatial digital infrastructure for historical archaeology. We introduce a next generation HGIS, which we term a historical spatial data infrastructure (HSDI), and then demonstrate the ways that it may serve as the basis for improving how archaeologists handle big data as well as changing geographic and temporal scale. The HSDI answers the call by González-Tennant (2016) for a more sophisticated employment of GIS in historical archaeology. Our HSDI particularly addresses issues of scale, which represent a challenge to the discipline of archaeology more broadly (Robb and Pauketat 2013), and are a major contributor toward the crisis of representation that has long dogged GIS-based archaeological research.

In the following section we review of the origin, structure, and construction process of an HSDI. This powerful, flexible infrastructure expands the scale of archaeological inquiry in a postindustrial urban environment, demonstrating how the use of an HSDI significantly improves historical archaeologists’ capacity for the discovery, visualization, and analysis of large amounts of detailed historical spatial data in complex contexts. While the focus of our case studies is urban and postindustrial, the basic principles are equally applicable to rural contexts as evidenced by the work of Van Allen and Lafreniere (2016), though the greater density and accessibility of historical records in urban areas admittedly permits a more fine-grained end product.

THE EVOLUTION OF GIS-BASED HISTORICAL SPATIAL RESEARCH

HISTORICAL GIS

Historical spatial data infrastructures represent the merging of Historical GIS (HGIS) practice with the principles of Spatial Data Infrastructures (SDI). HGIS is an interdisciplinary application of GIS to the study of the past that arose in the late 1990s and early 2000s (Gilliland 1998; Knowles 2000; Gregory et al. 2001; Holdsworth 2003). HGIS has subsequently developed into a distinct subdiscipline at the intersection of history and historical geography (Holdsworth 2003; Knowles 2016; Gregory et al. 2018a) and has influenced the development of the emerging field of spatial humanities discussed previously (Bodenhamer et al. 2010; Gregory and Geddes 2014; Gregory et al. 2018a). An HGIS typically consists of digitized and spatially referenced cartographic and non-cartographic records, allowing the mapping and visualization of large historical datasets such as censuses, tax records, boundaries, and gazetteers (Gregory and Ell 2007). The earliest uses of HGIS took the form of national-scale projects such as the Great Britain Historical GIS (GBHGIS), which began in the mid 1990s in the UK as a project to spatialize existing bodies historical statistical information, and subsequently focused on digitally modelling historical parish level boundaries to so as facilitate analysis (Gregory et al. 2002). Other national HGIS projects followed including examples focused on China (Bol & Ge 2005), Russia (Merzlyakova 2005), Ireland (Ell 2005), Belgium (Vanhaute 2005), South Korea (Kim 2005), and Canada (St-Hilaire et al. 2007). In the US, the Minnesota Population Center developed the National Historical Geographic Information System (NHGIS) to support the need for digitally reconstructed census boundaries for historical population research (Fitch and Ruggles 2003).

HGIS researchers subsequently saw the need to zoom in, beyond the large areal units of census geographies like parishes and counties, to the scale of the individual. The first example of this the was Montréal l'Avenir du Passé (MAP) project, an HGIS containing a sample of spatialized census, tax roll and city directory data for three time periods (1846, 1880, 2000) in Montreal's history (Gilliland and Olson 2003; Sweeney and Olson 2003). The sample consisted of those households with surnames beginning

with the letter 'B', with the data being spatialized at the resolution of individual city lots using digitized and georectified historical cartographic sources. Researchers have used the MAP HGIS to demonstrate that different forms of segregation were lived at different geographic scales (Gilliland and Olson 2010, Gilliland et al. 2011); to more clearly trace the daily lives of women in the industrial city (Gilliland and Olson 2010; Olson and Thornton 2011; Olson 2018); and to understand how events such as fire (Gilliland 2012) or street widening (Gilliland 2002) impacted urban development in Montreal. DeBats (2008) improved the resolution and increased the scale of HGIS research still further, by mapping the entire populations of Alexandria, Virginia in 1859, and Newport, Kentucky in 1874 using census, city directory, voting, and tax records. As with the MAP project, demographic data are mapped to the lot level. While this HGIS covers just a single year for each city, DeBats (2008) demonstrates the practicability and research value of spatializing entire city-scale historical record sets. DeBats' HGIS research ultimately revealed how wealth inequality manifested itself within complex representations of historical landscapes; it also highlighted the electoral dynamics and political consequences of segregation. (DeBats 2011; DeBats 2018).

The most recent HGIS research has increased the spatial resolution of HGIS approaches still further. Dunae et al. (2011) have constructed an HGIS for the city of Victoria, British Columbia that spatializes individual census information down to individual building footprints rather than lots, allowing researchers to place people within their actual homes (Dunae et al. 2011). To do this they rely, just as historical archaeologists typically do, on fire insurance plans, which are among the most detailed historical maps available in the historical record (Bloomfield 1982). The resulting HGIS, called the VIHistory HGIS project, combines the recreation of multiple time periods (1881, 1891, 1901, 1911) with the comprehensive city-scale demographic and geographic coverage of DeBats' HGIS research; the Victoria HGIS additionally includes municipal census data as both a check on and an augmentation of the national census data (Dunae et al. 2013). Using the Victoria HGIS, researchers have challenged the conventional narrative of Victoria's historical Chinatown as a community closed to outsiders (Dunae et al. 2011), "reconstructed the social and domestic spaces" of

industrial wagedworkers (Dunae et al. 2013:38), and disproved the longstanding assumption that indigenous peoples simply “vanished” as the city developed (Lutz et al. 2013; Lutz et al. 2018:336).

The Imag(in)ing London HGIS (<https://www.historicalgis.com/london-hgis.html>) improves upon the lessons learned during the creation of the HGIS projects focused on Montreal and Victoria by modelling the city of London, Ontario, and its surrounding rural countryside, within an HGIS. Lafreniere and Gilliland (2015, 2018a) incorporated eight time periods (1855, 1881, 1888, 1907, 1915, 1926, 1958, and a representation of the present-day city) within the Imag(in)ing London HGIS. Imag(in)ing London also achieves full city-scale coverage in its representations of past environments. This includes a detailed model of the built environment: human-made spaces in the city such as structures, land use designations, transportation systems, and parks, all digitized and spatialized from historical fire insurance plans and other cartographic sources. Linked to the built environment are the typical demographic sources used in previous examples, such as the decennial census and city directories, but also new sources such as small samples of school records, congregational records, and spatialized diaries (Lafreniere and Gilliland 2015). The Imag(in)ing London HGIS allows researchers to uncover small-scale activities, such as daily journeys to work and school as well as social mobility, either individually or in aggregate (Lafreniere and Gilliland 2018b). Doing so reveals the spatial patterning of social phenomena, such as how far from work people of certain occupations tended to live (Lafreniere and Gilliland 2018a); the likelihood that children of a given socioeconomic status will be exposed to noxious industrial environments during their walk to school (Lafreniere and Gilliland 2015); the role post offices played in the creation of social networks (Van Allen and Lafreniere 2016), or to model the changing geography of retailing through the 20th century (Novak and Gilliland 2011). The Imag(in)ing London HGIS not only represents the state of the art in HGIS research, but also a transitional stage towards the development of a fully-fledged HSDI, as we will outline below.

SPATIAL DATA INFRASTRUCTURES

We apply SDI principles to HGIS to meet challenges such as these. The U.S. National Research Council (NRC) coined the term *spatial data infrastructure* in 1993 in recognition for the need for national-scale infrastructures for facilitating the creation, use, and sharing of geospatial data, especially within the context of GIS (National Research Council 1993). The NRC defined an SDI as the “means to assemble geographic information that describes the arrangement and attributes of features and phenomena of the earth”, including the “...materials, technology, and people necessary to acquire process, store and distribute such information to meet a wide variety of needs” (NRC 1993:2). A key feature of any SDI is the creation of a collaborative organizational structure for managing knowledge about a particular space and ensuring data interoperability, standards, reliability, and accessibility. The US established an official National Spatial Data Infrastructure (NSDI) by executive order shortly afterwards (Clinton 1994), and by the end of the 1990s, numerous other NSDIs had appeared worldwide (Masser 1999).

While these early efforts were explicitly national in scale (Masser 1999), most of the actual data within NSDIs were provided by state and local institutions (Craig 2005). Within a decade states began to adopt the SDI concept themselves, following the lead of several pioneers such as Minnesota (Arbeit et al. 2004; Craig 2005), and the SDI approach has since come to be applied more broadly to a variety of circumstances where the need for a framework for the creation, use, and exchange of spatial data is felt (ESRI 2010; Masser and Cromptoets 2015). Within the historical sciences, the SDI *concept* has been used by historical demographers to the creation of big data historical demographic research infrastructures, most notably the Canadian Century Research Infrastructure (Gaffield 2007), the North Atlantic Population Project (Ruggles et al. 2011; Thorvaldsen, 2011), and the Minnesota Population Center’s longstanding development and dissemination of very large-scale yet highly detailed demographic data such as the

Integrated Public Use Microdata Series (IPUMS) (Sobek et al. 2011; Ruggles et al. 2015; Ruggles et al. 2017).

HGIS has thus evolved into a sophisticated and effective approach to studying people and their environments in the past from a spatial perspective. While successful as a research approach for geographers, historians, sociologists, and historical demographers, the use of HGIS for studying the past is not without challenges. Chief among these is that researchers have thus far struggled to scale HGIS beyond single specific projects. A lack of established standards for constructing HGIS results in researchers constantly reinventing the wheel (Knowles and Hillier 2008) with each new project, an issue that has also presented itself in archaeological applications of GIS (De Roo et al. 2013; González-Tennant 2016; Gillings 2017). The SDI approach effectively addresses this concern through the establishment of standardized data protocols and data/metadata formats under the leadership of institutions such as the Federal Geographic Data Committee (<https://www.fgdc.gov/standards>), eliminating the costly and time-consuming construction of a bespoke HGIS infrastructure for each new project.

FIGURE 1. Location of London, Ontario, Canada. (Illustration by Author, 2018.)

TOWARDS AN HSDI: THE IMAG(IN)ING LONDON HGIS

The Imag(in)ing London HGIS, briefly described previously, represents a transitional move towards the creation of a true HSDI. By creating discrete *built* and *social* environment “stages” that are then linked together into a highly complex digital historical infrastructure using geodatabases¹, Lafreniere and Gilliland’s (2015:2) approach brings to GIS-based studies of the past the scale, robustness, and accessibility of the SDI. Reviewing the construction and organization of the London HGIS demonstrates how the merging of HGIS and SDI approaches permits an expansion in the scale of inquiry into past environments.

The Imag(in)ing London HGIS is a high-resolution longitudinal HGIS recreation of the city of London that covers approximately 163 square miles of urban space as well as another 900 square miles of surrounding countryside and features a detailed model of the built and social environments for the period from 1855 to the present. In common with many rustbelt cities of the Great Lakes region, London (Figure 1) experienced a steady, occasionally rapid, process of industrialization over the course of the 19th and early 20th centuries, followed by a gradually accelerating decline in the latter half of the 20th century. Cities serve as excellent laboratories for GIS-based historical research (DeBats and Gregory 2011), and thus are ripe for the development of the HSDI concept, due to their voluminous documentation in the historical and cartographic record and their dense and relatively compact nature. Postindustrial cities are especially challenging, with dynamic processes of industrialization and deindustrialization resulting in highly complex, deeply layered and often contested histories (Mallach 2016; High et al. 2017); these complex histories are also reflected in their archaeology (Praetzellis and Praetzellis 2004; Rothschild and Wall 2014; Ryzewski 2015). GIS is already well established as a tool for urban planning and development (Yeh 2005). Access to an HGIS may serve to inform city planners, engineers, and the public alike, enabling these groups to adopt heritage-led development approaches, based in evidence, that are more likely to be sensitive the historic character or heritage values within a given community.

THE STRUCTURE OF THE IMAG(IN)ING LONDON HGIS: THE BUILT ENVIRONMENT STAGE

As with any HGIS, the Imag(in)ing London HGIS harnesses the principle that space is a powerful unifying element to conduct more effective historical research. Doing so begins with the digitization and spatial referencing of historical cartographic data, to create a *built environment stage*. Historical cartographic sources such as fire insurance plans (FIPs), topographic maps, and other cartographic sources are scanned at high resolution, georeferenced, and stored within a geodatabase. Large map sets using many individual sheets, such as the FIPs and geodetic surveys, are assembled into raster mosaic datasets, so that the entire set of sheets can be viewed and manipulated as one spatial dataset with seamless borders (Lafreniere and Rivet 2010).

FIGURE 2. Built environment stage preparation workflow for the Imag(in)ing London HGIS, adapted from Lafreniere and Gilliland (2015). (Illustration by Author, 2018.)

Built environment features such as building footprints, roads, and rail lines are manually digitized from the georeferenced historical cartographic sources as points, lines and polygon vector data and stored as feature classes in a geodatabase. Lafreniere and Gilliland (2015) then added relevant attribute data to each feature such as the building address, number of stories, building material, and any other specific information contained within the cartographic sources (including the name of the company occupying the building, the building's labeled function, the name of a street, or the owner of a section of railroad line). This process is then repeated for additional cartographic sources and divided into eight time periods or time slices that together cover over 100 years of changes to London's built environment. The HGIS also includes modern building footprints, land-use data, and other urban amenities created for the City of London's municipal GIS. The built environment stage of the London HGIS contains over 120,000 historical building footprints and thousands of roads and other built environment features (Figure 2).

This longitudinal structuring of the built environment stage permits features of the built environment to be spatially linked through geographic location or proximity as well as through linked attributes in the geodatabases such as street addresses, names of occupants, functional descriptions of a building, or details about land use. The historical maps themselves remain present in digital, georeferenced form, providing not only a visual backdrop to the vector data but also as primary sources against which other data may be compared and contrasted, looking for patterns and discrepancies worthy of further investigation. Within the Imag(in)ing London HGIS, the built environment stage thus represents a longitudinal recreation of London's historical buildings and infrastructure, using GIS raster and vector data that can be visualized in either 2D or 3D (Novak and Gilliland 2009; Lafreniere and Gilliland 2015; Arnold and Lafreniere 2018).

THE STRUCTURE OF THE IMAG(IN)ING LONDON HGIS: THE SOCIAL ENVIRONMENT STAGE

The built environment stage not only serves as a model of the historical built environment in its own right, but also serves as the basic spatio-temporal framework within the HGIS, to which a wide variety of additional data can be linked in the form of

additional HGIS stages. The Imag(in)ing London HGIS includes a social environment stage that links a large corpus of historical records containing demographic information on individuals and groups to the built environment stage. The social stage itself is anchored by the digitization of historical city directories and decennial census data that match the date of the built environment stages as closely as possible (see Lafreniere and Gilliland 2015). The city directories are digitally transcribed and then geocoded, with each line (representing an individual) in the directory assigned to a vector point within the HGIS corresponding to the centroid of a building polygon within the built environment stage that has a matching street address. Thus, the information contained in each year's directory is mapped to the residential addresses identified within the built environment stage, situating the information within the HGIS in both space and time. Once this process is complete, the contents of the decennial census nearest to each time slice can be added through the use of probabilistic record linkage software, as explained elsewhere by Lafreniere and Gilliland (2018a). Adding further historical sources (such as employee, school or congregational records) to Imag(in)ing London becomes possible due to the ability to match new data to existing geocoded social environment datasets by a host of variables including name, address, or employer. As more datasets are added, this process becomes progressively easier. Once available, this group of datasets collectively allows us to model a wide variety of detailed social environments in great detail; this includes families, professional or workplace networks, religious communities, schoolmates, and wider kin networks (Lafreniere and Gilliland 2015) (Figure 3).

FIGURE 3. Social environment stage preparation workflow for the Imag(in)ing London HGIS, adapted from Lafreniere and Gilliland (2015) (Illustration by Author, 2018.)

REALIZING THE HSDI CONCEPT: THE COPPER COUNTRY HSDI

The technical demands of the Imag(in)ing London HGIS, with its large geographic coverage and use of a wide variety of sources, led to the development of the dual built environment/social environment stage approach and the establishment of clear workflows and protocols for the production of a sophisticated HGIS (Lafreniere 2014; Lafreniere and Gilliland 2015). This structure foreshadows the SDI approach, but it has been left to a recently launched HGIS project, the Copper Country Spatial Data Infrastructure (CC-HSDI), to formally embrace the SDI concept for HGIS research for the first time (Trepal and Lafreniere 2018). The CC-HSDI is a fully-featured HSDI that covers the Copper Country region of Michigan’s Upper Peninsula, comprising Keweenaw, Houghton, and portions of Baraga and Ontonagon counties. Beginning in

the 1840s, large-scale exploration and development of a unique deposit of pure or *native* copper in the Lake Superior basin grew, through a series of booms, into the world's most productive copper mining region by the 1870s (Krause 1992). The region's mining industry entered a slow decline after World War I, with the last large-scale mining ending during the 1960s (Lankton 1991). Today, the Copper Country exists as a postindustrial landscape of former boom towns surrounded by a rural hinterland with an economy dependent on service industries and tourism. The project area includes several substantial towns covering about 50 square miles and numerous smaller villages set within over 2,000 square miles of rural, mostly forested land covered with thousands of mining-related archaeology sites such as mine openings, transportation infrastructure remains, ruined mills, and large waste deposits (Figure 4).

FIGURE 4. CC-HSDI Project Area. (Illustration by Author, 2018.)

The CC-HSDI improves upon the stage-based approach of the Imag(in)ing London HGIS in the following four crucial aspects; these may be considered the distinguishing features of an HSDI versus an HGIS, and together they permit the three expansions of scale mentioned previously.

1. *Flexibility of Inquiry:* Whereas the Imag(in)ing London HGIS was originally conceived as a tool to support a specific research question (historical social mobility in London), the CC-HSDI is designed from the start as a general purpose, interdisciplinary set of tools, data, and approaches to historical spatial research that will support research

into many different research questions. Providing such flexibility begins with the composition of the research team; the CC-HSDI is the result of a collaborative effort between over a dozen researchers with expertise in historical geography, historical GIS, public history, historical architecture, heritage management, archaeology, education, enterprise spatial database management, software engineering, web-based GIS, citizen science, and software human-interactive design. This is precisely the kind of interdisciplinary collaboration and cross-disciplinary training that archaeologists have recognized as essential for more effective use of GIS and exploitation of the digital humanities within archaeology (González-Tennant 2016; Brouwer Burg 2017; Earley-Spadoni 2017).

2. *Comprehensiveness*: the earlier manifestations of HGIS models described previously were built around specific datasets to answer specific questions or sets of questions. The CC-HSDI not only incorporates a wider variety of historical big data sources and types than previous implementations of HGIS, it is also intended to grow indefinitely as new bodies of historical data or new types of sources become available, whether that be through further digitizing projects or the availability of new sensor technologies or crowdsourced data. Further, an HSDI can easily link to open-source government data through the use of API's or REST URLs, as exemplified by the Scholars Portal (<https://scholarsportal.info/>), an SDI that provides access to a wide variety of data contributed by 21 university libraries within the Canadian province of Ontario. An HSDI is built with a suite of historical geocoders, gazetteers, and text parsing tools that allow researchers to quickly include nearly any source they locate in an archive or research repository in accurate time and space. For example, the CC-HSDI incorporates much larger bodies of school records than the Imag(in)ing London HGIS and also introduces tens of thousands of digitized and spatialized individual employee records, semiannual physical exams, and epidemiological data produced by historical mining companies and hospitals within the Copper Country.

3. Spatio-temporal Robustness: The CC-HSDI supports spatio-temporal data exploration and analysis. While the Imag(in)ing London HGIS (and other HGIS models) contain numerous time slices, these were designed primarily for looking at cross sections, or ‘snapshots’, of time. The CC-HSDI’s structure is explicitly designed so that data within the infrastructure is interlinked through both space and time using a combination of several different shared attributes. In particular, built environment features are tracked through a combination of spatio-temporal coexistence and attribute data that record when changes are made to a structure such as an addition to a building or the construction of a railroad spur line. Socio-demographic data, such the census, city directories, and company and school records are georeferenced within the actual building footprints of the residences, businesses, factories, and institutions representing the time period of the source material. Each individual is then linked to their various social environments, such as the rest of their family, their neighborhood, their workplace, and classroom, as well as linked (when possible) to their record in other historical datasets from the same period in time as well as forward and backward in time. HSDIs are therefore designed explicitly to study change over time in built and social environments on a variety of spatial scales rather than simply looking at certain phenomena at discrete times and places in the past (Figure 5).

FIGURE 5. Multiple data linkages within an HSDI (Illustration by Author, 2018.)

4. Accessibility: The core of the CC-HSDI consists of several enterprise geodatabases that can be accessed by the entire CC-HSDI research team, academic collaborators, and, most importantly, the general public using the internet. The public face of the CC-HSDI is represented by the Keweenaw Time Traveler (KeTT) project, the primary goal of which is to offer the public access to the CC-HSDI's historical big data through a user-friendly web interface (Scarlett et al. 2018). This is a Public Participatory Historical GIS (PPHGIS) project in which the public are collaborators rather than passive receivers of information (Lafreniere et al. 2019). Anyone may use the web interface to help to build the CC-HSDI through digitization and transcription of historical maps (georeferenced and served over the web by the KeTT team) as well as contributing their own spatially referenced oral histories and historical photographs (Scarlett et al. 2018). The KeTT user interface itself has been created in collaboration with the public through a series of design charrettes and outreach events that have provided valuable feedback. Public Archaeology is often still conceptualized in terms of site-based outreach and engagement (Richardson and Almansa-Sánchez 2015); an HSDI-based, publicly-oriented web interface such as the KeTT can bring sophisticated models of past environments to a much wider group of participants, allowing the public to explore and interact directly with historical big data, and even contribute to the HSDI's expansion. Between the design charrettes and the PPHGIS components, an HSDI can be used as a tool to meaningfully engage the public in the "construction of knowledge", a crucial component of public archaeology that is all too often not achieved in practice (Richardson and Almansa-Sánchez 2015:202)

The result of these improvements is a true historical spatial data infrastructure that links voluminous, yet disparate, components of a region's historical record in time and space within a web-accessible platform. The facility with which an HSDI handles the challenges of geographic scale, temporal scale, and the scale of historical big data permits an effective big data-based approach to the study of past built and social environments from multiple disciplinary perspectives. Ongoing developments in the ability for geodatabases to handle wider varieties of media ensure that any piece of

historical information can be incorporated so long as it can be linked to a person, place, or object within the HSDI. In the next section we use several brief case studies to highlight how we may begin to expand the scale of archaeological research by improving historical archaeologists' capacity to discover, visualize, and analyze historical data. This expansion of geographic, temporal, and data scale is accomplished in three different ways, each of which demonstrated briefly using examples from the postindustrial and urban landscapes of the Imag(in)ing London HGIS and CC-HSDI.

EXPANDING SCALES OF ARCHAEOLOGICAL INQUIRY: EXAMPLES FROM IMAG(IN)ING LONDON HGIS AND THE CC-HSDI

Using an HSDI helps address challenges of scale in historical archaeology in several aspects. It can move flexibly between extremes of geographic scale; it supports effective representations of change over time (temporal scale); it provides archaeologists access to a big data-scale representation of historical environments by digitizing, spatializing, and interlinking the historical record.

EXAMPLE 1: AUGMENTED GEOGRAPHIC SCALES OF RESEARCH IN LONDON

For example, the HSDI aids in the construction of narratives that flesh out and contextualize the microhistories of archaeological sites. Historical archaeologists often construct micro narratives based around the former occupants of the sites they study (Orser 2017). These may differ from micro narratives constructed by historians because, as Rebecca Yamin has argued, while historians are often selective in their use of documentary evidence, “archaeologists seek to include as much of the data as possible.” (Yamin 2001:167). Yamin explored the use of semi-fictionalized narratives as a means to create alternative narratives for an archaeological site or within a historical neighborhood, narratives that came closer to an insider's view of these historical places (Yamin 2001).

An HSDI is especially useful for the crafting of microhistories around archaeological sites and their former occupants with the aid of historical big data, and to

link those microhistories to broader historical and spatial contexts. Historical archaeologists often find the incorporation of microhistories into broader narratives challenging (Cantwell and Wall 2001; Mayne and Murray 2001). The HSDI allows us to bridge this gap in scale, and, at least with respect to the historical record, support the more comprehensive use of data Yamin (2001) mentioned while still leaving plenty of room for the construction of engaging, evidence-based narratives of daily life.

FIGURE 6. Visualizing microscale HSDI data: Richard Matthews’ family and home in London, Ontario. (Illustration by Author, 2018)

The Imag(in)ing London HGIS incorporates a big dataset of detailed records of individual activities useful for narrative-building, including twelve personal diaries that have been transcribed, parsed, and spatialized within the Imag(in)ing London HGIS. Here we use the example of the diary of Richard Matthews to show how the HSDI provides a link between archaeology-scale microhistories (Figure 6) and broader historical contexts. Matthews, a London postal clerk and father of six, kept a diary for 36 years. The Imag(in)ing London HGIS contains a spatialized two-year extract of this diary covering the period 1881–1882; 90% of the events and 70% of the people mentioned in the diary for that period have been successfully geocoded and linked to the other datasets within the Imag(in)ing London HGIS (Lafreniere and Gilliland 2015).

FIGURE 7. Contextualizing Matthews' household and home within his neighborhood. (Illustration by Author, 2018)

Richard Matthews's diary, as spatialized within the HSDI, provides an extremely detailed historical spatio-temporal environment within which we could contextualize the results of a hypothetical archaeology investigation at the Matthews's home site within his neighborhood (Figure 7). Reverend J. Allister Murray, who occasionally preached at Matthews's church, lived less than a block away at 356 Queens Street. William Scott Philips, one of Richard Matthews's fellow employees at the post office, lived on the same block as Matthews; they occasionally shared their morning commute. The spatio-temporal information within the diary is highly detailed; we know, for instance, that on Thursday, 5 October 1882 Richard's wife, Jane, received a visit at 9:35am from her friend and neighbor Elizabeth Raymond, a music teacher. Looking at the previous weeks' worth of entries, we can easily imagine them discussing other recent events in

the diary, such as Richard mixing up his dates and missing his lodge meeting, the recent renovations to their church, and a comet that appeared in the sky that week.

Zooming out spatially, an archaeological investigation at the Matthews's house lot could further benefit from the Imag(in)ing London HGIS to connect the archaeology to the Matthews family's actual life events and routines at broader spatial scales.

Matthews recorded his daily commute and work routine in some detail. He also recounts, and through the linked big datasets we can map and better observe, the variety of other activities such as his membership in the Ancient Order of United Workmen, picnics in the suburbs, dining out, attending a lecture on Roman history, and where and when he voted in local elections. We can also spatially flesh out the Matthews family's social spaces from the diary by mapping visits to and from the family home; the HSDI allows us to visualize events as they played out on the historical landscape over a period of time. We can thus link the Matthews family's spatial stories more broadly to the city of London. Finally, these micro narratives can also be focused around material culture itself. We can track some of Richard Matthews consumption patterns by tracing where and when he purchased his clothes, had his hair cut, and did his Christmas shopping (Figure 8). It also provides clues as to his material surroundings at home and at work. This record of consumption and material culture can serve as a valuable comparative to the archaeological record if we were to excavate Matthews's house or the post office where he worked. This dialogue between what was recorded and what remains in the archaeological record can aid us in asking more fruitful questions about what each body of evidence is telling us, and better identify where each might be biased or incomplete.

Scale: City

Richard Matthews' Spatial Stories: 1881

FIGURE 8. Contextualizing Richard Matthews' activities at the city scale. (Illustration by Author, 2018)

While diaries such as that of Richard Matthews only exist for a handful of people in the city, such sources each reference hundreds of other individuals, most of whom may be linked by name, address, and other attributes to personal records in other datasets within the HSDI. The census and directory data within the HSDI allows us to quickly and easily learn about all of these people: their age, sex, workplace, occupation, ethnicity, that of their families, and even their family's friends, relatives, and coworkers. Matthews's work at the post office links him to over 700 other postal employees in London for which we know their workplace duties, wages, employment histories, where they live, their family composition, etc. Church records contextualize Matthews

religious life through the activities of his parish at the Dundas Street Centre Methodist Church. With the HSDI we can quickly visualize and explore a highly complex web of social interactions and spatial movements around Richard Matthews and his family; thus, each diary may serve as the foundation for hundreds of microhistories beyond that of the original author, and as links to hundreds of other historical or archaeological sites.

This approach is of course also applicable to many other detailed historical sources such as school and employment records that may contain notes of events and routine activities, or sales ledgers or private account books that record consumption patterns. Archaeology and historical research may even become more closely intertwined on occasion when archaeologists find documentary evidence within a historical structure itself or within subsurface deposits, such as the ledgers Brace VI (Brace VI and Ellens, 2015; Brace VI 2016) found while documenting the blue Bird inn in Detroit. Using the HSDI, we can use spatial or tabular searches to quickly locate people, places and events recorded in those sources, construct micronarratives of activities and people associated with the site, and then link them to other people, places and events in the city.

EXAMPLE 2: AUGMENTED TEMPORAL SCALING

Societies and their environments are always dynamic; while researching a static ‘snapshot’ of the past will always be useful, archaeologists are also concerned with revealing and understanding change over time. As mentioned previously, incorporating the passage of time into GIS-based research has long been a challenge, and the methods proposed to meet this challenge differ depending on the kind of questions being asked and the time scales involved. For archaeologists, the tracking of change through time starts at some point in the past and typically ends at some other point in the past, or, perhaps, in the present. Many promising methods for collecting space-time data, such as the use of GPS transponders to track the movement of people, or the locational data available from Twitter (Goodchild 2013), are not useful for archaeologists whose subjects have often been dead for generations. For archaeologists, subjects are tracked

through combinations of archaeological and historical evidence. Tracking change through time through a rich, mutual contextualization of spatial historical big data can be accomplished within an HSDI, and this approach is adaptable to the needs of archaeologists. To illustrate, we return to the CC-HSDI to observe how it permits longitudinal linkages between data, the CC-HSDI relies on both tabular and spatial linkages of data between different time periods.

Identifier Type	Links To:
Join ID	Same building footprint “state” in different time slices
Street Address	All other HSDI data with matching address information
Date	All other HSDI data in same HSDI time slice
Place	All other HSDI data in same "place" (usually town name)
Global ID	Unique for each building footprint polygon in HSDI

Table 1: Key Attributes: CC-HSDI Built Environment Stage Data.

Within the CC-HSDI, each object within the built environment stage can be located using a variety of tabular queries (Table 1). Each building footprint is assigned a unique ID number during the digitization process that remains the same across time slices until the building is altered, demolished, or moved. In such cases, a new unique ID number is assigned that denotes the historical date in which the change to the structure occurred. Each unique ID number thus corresponds to a discrete structural ‘state’ of one component of the built environment that may persist over time in the form of multiple polygons originating from different time periods that occupy the same space and have the same ID, even though the address and the occupants may change. This allows for the quick identification of either persistence or change in the physical state of a building across time within the tabular data. Secondly, each building footprint in the HSDI is assigned a street address, date, and place (typically a town or county name) from its cartographic source. Built environment information can be filtered for objects containing that attribute or group of attributes, such as outbuildings at the same address, and can

also call up any social environment state data (such as census, city directory, school, or employment data) linked to that address from any time period covered by the CC-HSDI. Finally, each building footprint polygon is assigned a unique global ID within the CC-HSDI enterprise geodatabase, ensuring that every individual ‘object’ within the CC-HSDI’s global built environment stage is assigned a unique identifier. In each case, these tabular queries are useful for exploring the contents of multiple historical datasets covering a dense urban environment.

A more powerful way to visualize multiple objects across time is accomplished using the ability of the HSDI to spatially select and visualize data. Spatial queries are especially useful for tracking change over time because they can aggregate all of the available data within a flexibly defined location regardless of date or data type and without relying on tabular linkages, which must be constructed before they can be used. Spatial selections based on the intuitive visualization of the data within GIS are made within the GIS GUI using standard spatial selection tools. In this way we can visualize and identify new patterns in the data that may not be evident when looking at tables of historical data. This is also useful when address or occupant data are incomplete or missing, or a building never had an address assigned in the first place. The latter is often the case for industrial buildings within a larger complex, as exemplified by the copper mill complexes built by the Calumet & Hecla Mining Company in Lake Linden within the CC-HSDI. Using the HSDI we can visually identify and then select a specific mill complex, part of a complex or a combination of the industrial complex and surrounding residential neighborhood from the built environment data. We may then observe changes to the built environment or linked tabular data through time without having to rely on multiple tabular queries across time slices (Figure 9). With geographic space as a constant, we can visualize a given place as either a moment in time or as a palimpsest of cumulative built environment information recorded in the HSDI’s datasets.

FIGURE 9. Portion of Calumet & Hecla copper mill complex in Lake Linden, Michigan. Spatial queries can be used to locate changes across time to the industrial site without relying on tabular linkages across multiple datasets. Similar queries could highlight removal of building elements as well. (Illustration by Author, 2018)

The ability to visualize and explore cumulative phenomena such as the formation of a postindustrial landscape are especially powerful when the temporal depth of the CC-HSDI is explored at the larger geographical scales discussed previously. Entire urban areas such as the neighboring towns of Houghton and Hancock can be observed as they developed through time at multiple scales, in both 2D and 3D, and with any combination of historical built and social data toggled on and off as desired (Figure 10). This grants us the ability to observe the changing landscape dynamically from multiple visual

perspectives, and within different contexts while retaining the individual-scale resolution of the spatial and tabular data.

FIGURE 10. Landscape-scale changes in the built environment of the adjacent copper country towns of Houghton and Hancock can be interactively and recursively explored using the CC-HSDI without sacrificing the benefits of the high-resolution of the constituent big historical datasets. (Illustration by Author, 2018)

This way of observing historical environments echoes Torsten Hägerstrand's (1970) time-geography approach, a diagrammatic visualization of the movement of people through space and time. Time geography has recently seen a resurgence as the power and capability of computer-based geographic research methods has improved. (Sui 2012; Castree et al. 2013). The HSDI approach improves on the basic concept of time-geography by allowing researchers to track complex moments of people through space and time using genuine historical big data to represent it subjects and their large and small-scale contexts.

An HSDI thus provides archaeologists with a powerful approach to visualizing and exploring big historical data across space and time while looking for patterns and relationships between people and things. The HSDI can, however, also be used to support spatio-temporal analysis. A final example, this time from the Imag(in)ing London HGIS, demonstrates further how HSDIs may be usefully employed for analysis by archaeologists studying postindustrial cities, who must cope with the large physical scale of industrial systems, processes and sites, and the complex development of the landscape over time. The Imag(in)ing London HGIS can be used to visualize the postindustrial landscape in ways that reveal their cumulative process of formation. To demonstrate this, we use information concerning historical industrial building use contained within the Imag(in)ing London HGIS's datasets to generate a high-resolution spatial model of industrial land use intensity over time. Using historical descriptive information present in both the built and social environment stages, we manually classify all building footprints from all time periods within the built environment stage into broad land use categories based on conventional zoning classification systems in use across North America (Hirt 2014). Each footprint then receives a base industrial activity intensity rank (Table 2). In the case of commercial and industrial building footprints, the built and social environment stage data usually include either the name of the occupant or the chief function of each building (such as "stable" or, in the case of a manufacturing operation, the type of products produced ("Cigar Factory", for example). This allows us to infer the presence of specific types of industrial activity or activities within specific building footprints.

The base intensity rank is multiplied by the area of each industrial building to obtain the final intensity ranking using the following equation:

$$\textbf{Cumulative Industrial Intensity of a Given Building} = (\textbf{Land Use Classification Intensity} \times \textbf{Number of years of activity}) \times (\textbf{Building Footprint Area} \times \textbf{Number of Stories})$$

The footprint of each building is calculated and multiplied by the building's number of stories to produce the building's area. Once this ranking is generated, the polygon shapefile is converted to a raster with each pixel (cell) containing an intensity

value. A cell falling on open ground will have a low ranking, while a cell within an area featuring industrial activity will receive a high ranking. We repeat this process for each time slice, so that the rankings for each cell of each of the resulting rasters can be summed in ArcGIS. Adding the values in corresponding cells for each time slice are gives this map of activity temporal depth, resulting in a new raster representing the cumulative intensity of industrial activity within the study area across the full temporal scope of the Imag(in)ing London HGIS. This allows the intensity rankings to be visualized as an interpolated surface, revealing patterns of cumulative industrial activity on the landscape (Figure 11).

Base Intensity Classification	Rank	Examples
Open Land	1	Municipal park, school playground
Residential	2	Single family home; apartment building
Commercial	5	Retail business; strip mall
Light Industrial	6	Creamery; printer
Infrastructure	7	Electrical substation; railroad trestle
Medium Industrial	8	Lumber mill; textile manufacturer
Heavy Industrial	9	Steel manufacture, pesticide manufacture

TABLE 2. Land use base intensity ranking.

FIGURE 11. Cumulative intensity of industrial activity in downtown London, Ontario from 1888 to 2018. (Illustration by Author, 2018)

By comparing this model with modern land use maps and imagery, archaeologists can quickly identify industrial complexes or districts that may be of particular interest, to search for sites of comparative intensity across the city, or to compare the intensities of multiple sites. This aids in quickly assessing the extent of past industrial landscapes manifesting in the present – revealing a city-scale landscape of intensive, persistent historical industrial activity in numerous sites that are either ‘lost’, partially extant, adaptively reused, or, in a few cases, still active. Specifically, archaeologists looking at a particular type of industry can quickly identify within the HSDI where all such operations were located within the city, when they were active,

and, by comparing this data with the modern municipal GIS data within the London HGIS, the current occupation or use of each site. This model could even be taken into the field and aid in reflexive, iterative explorations of the postindustrial landscape at every stage of archaeological research, bringing the archive to the field in a more effective way than was previously possible (Arnold, Lafreniere, and Scarlett 2018).

Time represents a crucial component of archaeological provenience, and digital historical environments such as an HSDI must be able to facilitate the visualization of time not only in discrete moments but as dynamic processes taking place at varying spatial scales. Tabular linkages in the geodatabases are important ways to link datasets across time. However, spatializing big historical data is the most powerful way to link disparate pieces of information across time, not only between various periods in the past, but also between the past and the present. Any contemporary information about the built and social environment of the Copper Country can be linked via the HSDI to a vast pool of historical data through geographic location, maintaining the crucial link between the past events being represented and studied on the one hand, and the contemporary physical landscape, the cumulative result of all of those past phenomena, on the other.

EXAMPLE 3: EMBRACING THE SCALE OF BIG DATA

The ultimate promise of the application of big historical data to historical archaeology is the development of more rigorous linkages between different scales of inquiry, from the micro scale to the neighborhood, district, city, region, and beyond, through the exploration and analysis of historical environments within an HSDI. Recently Kintigh et al. (2014) described grand challenges for archaeology that include the need for better computational infrastructure for modeling historical and ancient phenomena at larger geographic and temporal scales; scale remains a major challenge (Robb and Pauketat 2013). These challenges, as well as the challenges of reconciling different modes of space and representation when using spatial digital approaches (Lock and Pouncett 2017), are also relevant to historical archaeologists yet little conversation about them has taken place thus far within historical archaeology. General discussions of

big data issues within archaeology, such as the “avalanche” (Petrovic 2011:56) or “deluge” (Bevan 2015:1473) of incoming archaeological data, or the future role of geospatial big data (McCoy 2017), still tend to focus on more ancient contexts in their case studies. While the time scale of historical archaeology might be narrower, and the types of evidence available somewhat different, it is past time for historical archaeologists and digital historical big data to become part of the growing conversation about how to better integrate big data-based computational approaches within archaeology.

The development of the HSDI approach presents historical archaeologists with its own unique entrée into this discussion. Geospatial big data serves as the basic building blocks of an HSDI and, as demonstrated previously presents us with a geographically and temporally flexible digital infrastructure of the kind called for more broadly within archaeology. It is also ideally suited to the time periods historical archeologist study. This is not merely a new way to organize and store spatialized historical data, but also a big data-based historical environment within which spatial historians study the past. Historical archaeologists, as users of the historical record in their own right, can and should benefit from the potential benefits of spatial history approaches.

In the previous two examples, we have touched upon the various linkages between specific datasets and demonstrated the robust geographic and temporal scaling that the HSDI can support. Data linkages are both tabular and spatial, easing the task of identifying individual object, groups of objects with shared attributes, or spatial patterning, all at a variety of scales. Here we wish to emphasize the comprehensiveness afforded by these linkages as well as the modularity of this approach. This is especially evident in the social environment stage of the CC-HSDI, where the geocoded city directories and census data serve as a spatialized digital lattice for the incorporation of virtually any other historical data that can be linked to a person, household, address, or workplace, or even more generalized locations. The HSDI approach mutually contextualizes all of its constituent data on the built and social environments within space and time; with it we can model a historical landscape using the historical record to

a degree impossible outside a big data project (Figure 5). Such environments are useful for more efficient large-scale spatio-temporal querying of the historical record for the purposes of archaeological site location, the generation of research designs, or the formulation of research questions.

A simple illustration of this can be made using the CC-HSDI's social environment data. As an active mining region, the Copper Country attracted a large immigrant population, with nearly a quarter of residents in the five largest towns in the area in 1920 being foreign-born. Of these towns, Calumet, which contained the largest concentration of underground mining activity, had the highest proportion (33%) of immigrants among its population in 1920, over a third. For archaeologists seeking to contextualize the experience of immigrant labor within the broader community, the CC-HSDI provides us with a convenient and powerful tool for querying the broad spatial patterning of immigrants within the CC-HSDI. This allows archaeologists to contextualize their study area within those broad patterns, but also to zoom in to look at detailed contexts of potential sites at the household and individual level, thanks to the CC-HSDI's capacity to support the rapid aggregation and disaggregation of big historical data record sets.

For example, if we zoom in from our regional scale visualization to the scale of a street in the town of Hancock in 1917 (Figure 12), we can contextualize the neighborhood by looking at the national origin and occupation of the residents there. The data is displayed using a prototype web interface currently under development for the CC-HSDI known as the Keweenaw Time Traveler (<<http://www.keweenawhistory.com>>). For an archaeologist using the CC-HSDI, historical data exploration and visualization may be useful for the purposes of site location, as argued by White (2013); more than that, it is also excellent aid to the iterative construction of microhistories of a person, household, or neighborhood during the fieldwork and post-field analysis stages of the archaeological research process. Ultimately, big data provides a freedom of movement within the historical record that cannot be achieved by even the most rigorous traditional historical research methods as the HSDI's depth of data and temporality permits a flexibility of contextualization that allows us to continuously shift our frame of reference in space and

time. We can look at the same location from multiple spatio-temporal perspectives, or we can look for similar patterns formed by the interaction of several types of evidence in multiple times and places. This represents a far more interactive, flexible, and comprehensive approach to the historical record than the methods archaeologists typically employ.

FIGURE 12. Contextualizing the immigrant experience in space and time at the neighborhood scale. (Illustration by Author, 2018)

CONCLUSION

With GIS firmly established within archaeology, the continuing challenge archaeologists face is to understand how best to use it, and similar computational methods, in ways that will benefit archaeology and, through archaeology, the public. It has already proven itself indispensable for basic data recording and mapping; this will likely remain the most common application of GIS among archaeologists for the foreseeable future. The value of GIS as a means to conduct certain types of complex spatial analyses is also well-established – though less so in historical archaeology.

Recent discussions of the role of GIS in archaeology have, however suggested it is capable of much more than this. In particular, several of the most recent discussions of the use of GIS in archaeology (González-Tennant 2016; Howey and Brouwer Burg 2017a; Howey and Brouwer Burg 2017b) have concluded that GIS needs to move from being seen as a tool to being considered a practice or process; they have also argued that engagement with how other disciplines use GIS, such as the digital humanities and GIScience, will grant archaeologists access to useful new theoretical and methodological tools for improving the value of GIS to archaeology.

We argue that a crucial early step in the transition of archaeological GIS from tool to process is the establishment of methodologies and infrastructures such as an HSDI that can support the necessary interdisciplinary blending of the methodologies and theoretical tools of spatial history, digital humanities, and archaeology. These powerful, flexible spatial data infrastructures can serve to lower disciplinary barriers as well as the barriers between qualitative and quantitative forms of inquiry as they move well beyond the limitations of static representations in academic paper publications and represent dynamic, interactive, iterative spatial approaches to the study of historical environments. The ultimate outcome of this engagement may be the development of large-scale, longitudinal deep maps for archaeology that can support traditional GIS tasks such as data collection, storage, and management as well as rigorous geospatial analysis but yet, most importantly, are also capable of better representing lived experience and a sense of place. The HSDI thus may support a hermeneutic approach (Mayne and Murray 2001) to historical archaeology where historical and archaeological data are iteratively contextualized at different scales though all stages of the research process; this work may also involve creating imaginative, narrative components (Yamin 2001) or the use of virtual reality and collaborative digital storytelling (González-Tennant 2017). Achieving these goals requires close collaboration between archaeologists, historians, digital humanists, geographers and GIScientists others such as computer scientists, software engineers, and cartographers. Our research demonstrates a case study of such a collaboration. Using space as the fundamental integrating element, we have demonstrated how archeologists working in postindustrial urban contexts may apply the

HSDI approach to expand the scale of archaeological inquiry into historical environments by taking advantage of its facility in handling geographic scales, temporal scales, and working with big data more generally. Historical archaeology may, in turn, contribute to spatial history and the digital humanities our own unique perspective on the past, its manifestation in the present, and, perhaps most importantly, convey the value of material culture and archeological landscapes to other disciplines. Public web access to HSDIs like the Keweenaw Time Traveler bring these past environments to the public and represents another useful conduit for the wider dissemination and exchange of archaeological knowledge.

Of course, ‘doing’ archaeology requires resources, and those resources differ depending on whether archaeology is being conducted under the rubric of academia, federal agencies, nonprofit organizations, or for-profit cultural resource management. The HSDI approach we advocate requires substantial, long-term institutional support and cooperation with a range of other disciplines, and is clearly not within the reach of every archaeologist, anthropology department, or cultural resource management firm. It is not our intention to suggest that every archaeologist ought to start building an HSDI; rather, we wish to demonstrate the potential of the HSDI concept to archaeology in general, and historical archaeology in particular, and to encourage groups of researchers, CRM firms, or cultural institutions to collaborate with each other to secure the necessary resources to build and share these infrastructures. The CC-HSDI is accessible by the general public, and the research team maintaining it has also made the HSDI available to the academic community, regional non-profit organizations, and local municipalities. Our intention is to make the infrastructure as easily and widely accessible as possible. While the entire contents for the CC-HSDI are freely available, questions of how to provide access to costly, restricted-access, and/or sensitive data (de Kleijn 2014; Kitchin 2014) are a shared concern with all SDI projects and will require further evolutions of the HSDI interface and sharing model as those types of data are incorporated. Despite this, we demonstrate that a highly complex, fully functioning HSDI can be built with unrestricted public data, and public data will continue to serve as the foundation of the project.

Finally, we must remain mindful of the delicate balance required during any application of computational methods to the study of our own past. It is appropriate to summon the oft-quoted chestnut by George Box:

"...there is no need to ask the question "Is the model true?". If "truth" is to be the "whole truth" the answer must be "No". The only question of interest is "Is the model illuminating and useful?" (Box 1979:203)

As we work to improve the complexity and rigor of our modeling of past environments, it is important to remember that the best we can hope for are more useful or illuminating models, not perfection or “truth”. The HSDI is intended to substantially augment, not replace, existing approaches to understanding the historical record and the complex dialogue between historical and archaeological evidence that is so fundamental to historical archaeology. Given what archaeologists have achieved using GIS thus far, we believe this is a worthy and achievable goal. The embrace of an HSDI approach to GIS in historical archaeology is a search for new and better questions rather than the search for answers or “truthful” models per se. By making use of increasingly flexible, comprehensive, temporally robust, and accessible historical digital infrastructures, we seek to make available new perspectives on the data we have to work with by augmenting our established approaches. GIS itself will likely continue to live a double life within the broader discipline of archaeology for some time to come; its status as an indispensable tool continues to be consolidated by technological improvements, while the debate over its potential as a process is in some ways only just heating up. Recent applications of GIS continue to percolate from interdisciplinary spaces within the social sciences, however, and historical archaeology will benefit from participation in these more expansive approaches to the process of GIS.

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**UNDERSTANDING CUMULATIVE HAZARDS IN A RUSTBELT CITY:
INTEGRATING GIS, ARCHAEOLOGY, AND SPATIAL HISTORY**

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ABSTRACT

We combine the Historical Spatial Data Infrastructure (HSDI) concept developed within spatial history with elements of archaeological predictive modeling to demonstrate a novel GIS-based landscape model for identifying the persistence of historically-generated industrial hazards in postindustrial cities. This historical big data approach draws on over a century of both historical and modern spatial big data to project the presence of specific persistent historical hazards across a city. This research improves on previous attempts to understand the origins and persistence of historical pollution hazards, and our final model augments traditional archaeological approaches to site prospection and analysis. This study also demonstrates how an HSDI can help link archaeologists to other researchers and to municipal decision makers working in postindustrial cities, with benefits to archaeology, urban heritage, redevelopment, and environmental sustainability efforts in postindustrial cities.

KEYWORDS

Historical GIS, Postindustrial, Big Data, Archaeology, Urban, GIS

1. INTRODUCTION

This study demonstrates the application of a temporally linked, big data historical GIS (HGIS) or Historical Spatial Data Infrastructure (HSDI) to archaeological research in postindustrial urban environments. By taking a big data approach to the historical record, we contextualize past industrial activity in our case study city of London, Ontario (Figure 1) within a complex longitudinal model of past and present built and social environments, one that is both fine-grained and yet can also be used to identify patterns manifesting in these environments at the scale of the city. We demonstrate how this HSDI-based longitudinal model can be used to explore human risk of exposure to pollution at both discrete periods in the past as well as the cumulative effects on the contemporary postindustrial landscape. Archaeologists play an important role in the future of postindustrial cities due to the close relationship between contemporary social, economic and environmental issues on the one hand, and the material remains – and consequences – of past industrial activities on the other. Postindustrial cities are archaeological landscapes that bear witness to the complex processes of industrialization and deindustrialization; nowhere is this more apparent than in the rustbelt cities of the Midwest, where understanding the archaeological landscape can play a role in helping make sense of issues of environmental justice such as the Flint Water Crisis, or to better identify the hidden consequences of past industrial activity in postindustrial cities.

Archaeologists have a well-established expertise in understanding the complex, longitudinal social and material processes taking place in modern postindustrial cities – both above and below ground [1]. However, industrial pollution itself is generally seen by archaeologists as either a threat to archaeological remains [2-4], part of site formation processes [5], or as an occupational hazard to archaeologists themselves [6]. Moreover, in conceptualizing a modern city as itself an archaeological site with both micro- and macro-scale features and patterns of change [7], we immediately run against the challenges inherent in the adoption of an effective multiscale perspective taking in widely varying temporal and spatial frames; this is an issue that continues to challenge the discipline of archaeology as a whole [8]. These clearly represent obstacles for

archaeological inquiry. How can we organize and analyze the volume of historical data necessary to contextualize historical archaeology within the large-scale, extraordinarily complex, and dynamic landscape that is an industrial city? Archaeologists proved to be early adopters of GIS as a tool for prospection and analysis [9, 10], yet the use of GIS in historical archaeology remains underexploited and can benefit greatly by the use of GIS methodologies for the purpose of prospection, visualization, analysis and interdisciplinary collaboration [11]. We argue that one new implementation of GIS-based approaches to studying the past, namely the HSDI, can help meet that challenge by providing archaeologists with highly detailed yet scalable historical contexts for the more effective study of postindustrial cities. Our argument for the use of HSDIs in historical archaeology also serves as a potential component of a digital “grand challenge” towards building digital infrastructures for archaeology that represent contributions to “the broader epistemic and pragmatic contexts of archaeological work” [12] (p. 178). The adoption of a big data-based GIS approach also further exposes historical archaeology to the spatial turn currently driving much research in the social sciences [13-15].

FIGURE 1. The project study area encompasses the urban portions of London, Ontario across the period 1888 to present. Map by author.

Finally, our study serves as a link between the historical archaeology of postindustrial cities to a broader body of interdisciplinary scholarship that focuses on the legacies of urban industrial activity. Conceptualizations of industrialized cities as socio-

ecological systems identify the byproducts of industrial activity as an important component of such systems [16]. Olson [17] further argued that such work must take a historical focus and adopt a city-scale perspective to adequately understand such systems. This has led to a number of recent empirical investigations that sought to link historical industrial activity with potential pollution hazards or health risks in the modern landscape through the use of GIS-based research using historical records and cartographic data. In a pioneering study, Litt and Burke [18] demonstrated the use of GIS as a way to contextualize brownfields in southeast Baltimore within their surrounding neighborhoods, revealing the complex histories and potential health risks attached to former industrial landscapes. Using a combination of historical records of industrial facilities, pollution release and remediation data, and demographic data from census and municipal records, they linked past industrial activities (expressed using Standard Industrial Classification (SIC) codes) to likely specific pollutants in 182 brownfield sites over 1 acre within the study area from the period 1935-1997. When they compared the study area's census tract and municipal mortality data with city-wide and national averages, they found that the study area featured a lower average income and higher mortality [18].

Kolodziej et al. [19] also used historical fire insurance plans and modern municipal parcel data to map health risks on a postindustrial landscape within a GIS. Identifying the locations of past industrial operations in 1880, the 1960s, and 1997, Kolodziej et al. labeled each with an appropriate SIC code. Using federal pollution release data acquired from the Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS), they then ranked each on an ascending 1-3 scale for likelihood of generating persistent soil pollution. They then aggregated these scores within census tracts to identify "hotspots" of pollution risk. Both of these studies proved the concept of linking historical industrial activity with pollution or hazard risks; however, in both cases, the spatial resolutions involved were relatively gross (e.g., points within a GIS representing industrial operations and demographic data drawn from the census tract level). More recently, Hayek et al. [20] demonstrated how historical

documents, such as fire insurance plans and business directories, could be digitized within a GIS for the purposes of building a spatial database of brownfields.

Elliott and Frickle [21, 22] have recently demonstrated improvements to this basic approach in their investigations of industrial legacies in the city of Portland. Like Litt and Burke and Kolodziej et al. [18, 19], they used a GIS to map industrial activity longitudinally within an urban context. In mapping spatio-temporal patterns of industrial land use in Portland between 1956 and 2007, Elliott and Frickle noticed a pattern of industrial “churning”, or recursive industrial land use by multiple occupants in hotspots, alongside a slow expansion of industrial activity to new areas. Elliott and Frickle found that the lack of federal pollution release tracking of smaller industrial operations, coupled with changes in land use to non-industrial types, obscures the visibility of a substantial proportion of the potentially polluted former industrial land in Portland [22] (p. 528); Indeed, none of the sites they examined were considered brownfields, as all were occupied and in use, either for industrial or non-industrial purposes [22] (p. 538). Finally, they also noted that longitudinal mappings of industrial activity result in a very different spatial view of Portland’s potentially polluted land, as seemingly isolated modern hotspots merge into larger areas of temporally overlapping historical industrial landscapes [22] (p. 532).

Our approach begins where Elliott and Frickle’s ended, and in particular represents three improvements. First, we expand the temporal scope of our study to the 129-year period 1888-2016. Our study will capture the industrial history of London beginning during a period of rapid industrialization, through maturity and on through the period of deindustrialization to the present day commercialized postindustrial city. Second, our industrial site data is digitized from historical fire insurance plans to the resolution of individual building footprints and covers the entire city of London, a substantial increase in detail and comprehensiveness over the studies discussed previously. Third, we recognize that “industrial churning” [22] (p. 536) results in complex site histories, and also recognizing that many smaller industrial operations are often ignored in both the tracking of pollution release and the study of industrial legacies

[22] (p. 538). To address these issues, our study considers all industrial activity taking place in the city, including not only small-scale operations likely to have been missed in previous studies, but also certain commercial operations – such as gas stations and auto repair shops – that are not classed as industrial but that present risks of pollution. To accomplish this, we employ a novel GIS-based longitudinal model of London, Ontario.

1.1 NEW INFRASTRUCTURES FOR STUDYING INDUSTRIAL ACTIVITY ACROSS TIME AND SPACE

The foundation of our improvements in investigating industrial landscapes lies in the creation and use of a robust and flexible digital infrastructure that we refer to as a Historical Spatial Data Infrastructure (HSDI). We introduce the HSDI concept and describe technical details relating to its construction elsewhere [23]; in brief, it is a digital infrastructure that links the research benefits of Historical GIS with the flexibility, scalability, and robustness of Spatial Data Infrastructures (SDIs) that underpin critical big data projects such as the Minnesota Population Center’s Integrated Public Use Microdata Series (IPUMS) [24-26].

FIGURE 2. The London HSDI's built environment data includes over 116,000 manually digitized building footprints covering the period 1888-2016. Each footprint (shown above in green) is linked in the HSDI to detailed attribute information derived from historical fire insurance plans, business directories, and other archival sources. Image by author.

The Imag(in)ing London Historical GIS project [27] represents an early implementation of the HSDI concept [23] and this project (hereafter referred to as the London HSDI) forms the basis of the present longitudinal investigation of industrial hazards. The London HSDI consists of two environmental “stages”: the Built Environment (BE) stage and the Social Environment (SE) stage. The BE stage is a GIS-based reconstruction of London’s built environment derived from scanned and georeferenced historical cartography that have been vectorized in GIS and populated with attribute data from the source material including the building’s address, construction materials, number of stories, and occupant. The BE consists primarily of building footprints and road and rail networks (Figure 2). To date the London HSDI contains over 116,000 historical building footprints as well as a representation of modern London’s built infrastructure obtained from the City of London’s municipal GIS. The SE stage populates this virtual historic landscape with historical records of the population that lived in London, with each record geocoded to the person’s place of residence and linked to workplaces, schools, and institutional organizations each person can be linked to. We focus on the BE stage within the present study, although we will address the relevance of the SE stage to our findings subsequently in our concluding discussion.

2. MATERIALS AND METHODS

To develop our longitudinal industrial hazard model we substantially modified the existing London HSDI by mapping the industrial landscapes (past and present) in greater detail, integrating a set of real-world predictive pollution data into the HSDI, building the model using GIS-based spatial analysis tools, and finally checking the predictive hazard model against real-world remediation data.

FIGURE 3. Industrial activity within the London HDSI is recorded at the sub-building footprint resolution, identifying discrete historical activity areas within a building or building complex. Image by author.

2.1 MAPPING INDUSTRIAL ACTIVITIES AT FINER SCALES WITHIN THE LONDON HDSI

While the London HGIS BE data provides a highly detailed building-scale representation of past environments in London, it does not take full advantage of the resolution provided by the historical FIPs. Within the FIPs, dwellings and commercial buildings are often represented by a building footprint, with additions and major structure divisions often delineated. In the case of industrial buildings, especially larger industrial building complexes, the internal divisions are often shown in greater detail. For example, within the Empire Brass Foundry at 1108 Dundas Street in 1958 (Figure 3) we find that the FIPs record in detail rooms representing various stages of the brass founding process: a core room where sand and loam molds are prepared, a cupola

furnace room where brass is melted in preparation for casting, and the foundry floor where the molds are filled with brass and allowed to cool, and the machine shops and finishing rooms where the castings are machined and assembled into finished products. Producers of fire insurance plans such as the Sanborn and Charles Goad companies originally undertook this more detailed mapping of industrial structures because different industrial processes (of which there may be many within one industrial complex) produce substantially different fire risks. Thus, industrial complexes are often mapped at the sub-building level, with individual rooms or parts of rooms labeled with the specific industrial processes and equipment that occupied those locations. This is an extremely valuable resource for the archaeologist and historian; few historical sources map human activity over such a large area at such fine scales with useful accuracy. From an archaeological perspective, these distinct small-scale physical divisions of the industrial process can be likened to activity areas – areas devoted to a specific historical activity, in this case industrial activities such as the Empire Brass foundry, and it is here that the HSDI begins to connect to the micro-scale human activities fundamental to archaeology. Each of these rooms represents different industrial activity areas that incorporate different raw materials and human activities, and – most importantly for the present study – may represent point sources for very different hazards.

In order to incorporate this activity-area scale record of historical industrial activity into our industrial hazard landscape model, we undertook a process of augmenting the BE data within the London HSDI to capture this high level of detail within the HSDI. Rather than digitize industrial buildings and building complexes as building footprints as originally done when constructing the London HSDI, we digitized each labeled room or subdivision within the building or complex as a discrete polygon and transcribed data regarding the industrial activity taking place within each of these spaces from the FIPs. We then appended the full suite of attribute data (including building address, building material, and owner) for the overall building or complex to each of these rooms. This allowed us to the next step of construction of our predictive model, the mapping of hazards stemming from these industrial activities.

2.2 INTEGRATING REAL-WORLD POLLUTION DATA

As modified, the London HSDI is now capable of illustrating the spatial patterning of industrial activities across the city of London at four time periods (1888, 1915, 1958, 2016). In order to link these loci of industrial activity the likelihood for exposure to pollution at various times in the past, or for the persistence of historical pollutants on the contemporary landscape, we must link specific industrial activities with the potential emission of specific classes of pollutants. To do this, we link our mapped historical industrial activity areas to pollution estimates developed by the Industrial Pollution Projection System (IPPS). IPPS is the result of research conducted by the World Bank to aid developing nations in formulating environmental regulation [28] (p. I). The IPPS is based on the premise that the nature and scale of industrial pollutant emissions depend heavily on three factors [28] (p. I): 1) the scale of industrial activity; 2) the specific industrial sector involved; 3) the specific industrial processes in use. The IPPS was based on a sophisticated analysis of over 200,000 industrial facilities in the United States. Industrial activities were organized into sectors using the International Standard Industrial Classification of All Economic Activities (ISIC) code system at the four-digit level of aggregation. Industrial output data and other information for each of the over 200,000 facilities involved in the study were collected using the Longitudinal research Database (LRD), a digitized database derived from the Census of Manufactures (CM) (1963-1987) and the Annual Survey of Manufactures (ASM) (1973-1989) [28] (pp. 13-14). Environmental pollution data for each facility was collected by linking the LRD With five US EPA environmental databases tracking air, water, and soil pollution. Together, these datasets allow the IPPS to link several hundred thousand specific industrial facilities to the release of hundreds of specific air, water and solid waste pollutants based on real-world industrial output and pollutant discharge data (Figure 4) [28] (pp. 1-2). The basic concept behind the IPPS is the development of a “pollution intensity” ranking for each ISIC industrial sector, expressed as follows:

$$\text{Pollutant Output Intensity} = (\text{Pollutant Output}) / (\text{Total Manufacturing Activity})$$

For the numerator (pollutant output) Hettige et al. ranked all of the recorded pollutants emitted by the industrial facilities in a descending scale of toxicological potency (1-4, with 1 being the most hazardous) [28] (p. 21). They then multiplied the amount of each chemical released by a facility by its toxicological potency ranking, resulting in each release being expressed as risk-weighted pounds of toxic pollutants. Each of these individual risk-weighted results were then summed to establish a total risk-weighted release for each facility, and all facilities within a sector were summed to create the final sectoral totals [28] (pp. 22-23).

The IPPS used three different measures for the denominator (total manufacturing activity): total product shipment value, value added, and number of employees [28] (pp. 18-19). For our study, we selected the risk factor data using the employment denominator. Final risk factor tables for air, water, soil and toxic metal pollution types are included, as well as tables combining all four risk factors for each sector [28] (pp. 1-2). To help compensate for biases and lacunae in the datasets, Hettige et al. produced three sets of final estimates: upper bound, upper bound inter-quartile mean, and lower bound estimates. We have chosen to use the lower bound estimates in our research, because they provide the most complete set of risk estimates across sectors and pollution types; however, it must be noted that, of the three sets of estimates, the lower bound results are also the most likely to be biased downward in their estimates of pollution intensities [28] (pp. 20-21).

FIGURE 4. Industrial Pollution Projections System (IPPS) Workflow Illustration by author, after Hettige et al., 1995.

The IPPS has been successfully applied to project industrial pollution risks in developing countries [29], [30]. It has also proved to be popular as a source of sectoral industrial pollution estimates by researchers discussing issues relating to environmental regulation and economic development [31-36]. Though the IPPS was originally intended to project pollution risks in developing countries, the system is based on a uniquely detailed analysis of 20th century industrial output and pollution on the United States and is therefore reasonably well suited to historical investigations involving industrialized North American cities such as London. Incorporating the IPPS data into the London HSDI involved linking the IPPS total lower bound risk factors to each polygon representing an industrial building footprint, subdivision, or room within the London HSDI. To do this, we manually assigned to each polygon within the London HSDI an ISIC code that corresponded with the industrial activity documented within that space by the historical record.

Table 1. Zone-based extrapolated hazard factors.

Land Use Zone	IPPS Total Lower Bound Risk Factor (<i>kilograms of toxic byproduct / 1000 Employees</i>)
Residential	7879
Commercial	15758
Institutional	31516
Light Industrial	63031
General Industrial	85969
Heavy Industrial	1195628

2.3 DEVELOPING A ZONING-BASED PROXY HAZARD FACTOR

Because the IPPS focused on ISIC sectors related to industrial production and manufacturing rather than service or office activities, the result so f our ISIC coding step left us with a substantial number of polygons that could not be classified directly using an ISIC code linked to the IPPS. These were assigned a generic 4-digit code (9999). In order to apply our pollution analysis to the entire study area and all time slices, including non-industrial buildings and industrial buildings with a generic code, we developed a zoning code-based ranking system to which we could apply IPPS risk factor data. We simplified London's current zoning code into six zones (Table 1). Non industrial buildings were manually assigned an appropriate code (residential, commercial, institutional) based on the guidelines within London's current bylaws. For industrial properties with a generic four-digit code, we divided the ISIC sectors represented within the IPPS into the simplified light, general, and heavy industrial sectors derived from London's current zoning bylaws. We then calculated the mean IPPS risk factor value for each group to represent that zone's risk factor. We extrapolated a risk factor for institutional zone by dividing the light industrial risk factor by 2. We then applied risk factors to commercial and residential zones by dividing the institutional value

sequentially for each. This allows us to assign an IPPS-derived risk factor to industrial activities not directly considered within the IPPS itself. This also results in a risk factor that drops dramatically from heavy industrial to general and light industrial zones – a trend that replicates the results of the original IPPS data, where a small number of heavily polluting sectors produce a dramatically higher risk factor than the rest.

2.4 CREATING A PREDICTIVE MODEL

To spatialize the relative severity of hazards generated by industrial activity in London in each of our time slices, we incorporate the IPPS-derived risk factor data into our BE stage data in the form of a numerical hazard factor. To calculate this hazard factor, we multiply the IPPS or zone-based pollutant output numbers assigned to each polygon (representing kilograms of toxic produced by product per 1,000 employees) by the polygon's area in square meters. The area measurement thus serves as a proxy for employment figures for each historical industrial operation, which are not available within the London HSDI. As a result of this calculation each polygon within the London HSDI is assigned an IPPS-derived hazard factor expressed as kilograms of toxic byproduct per polygon. It is important to note that despite our use of IPPS data that is based on real-world observation of industrial pollution outputs, the final hazard factor used in our hazard model serves as a relative measure of industrial hazard rather than an attempt to estimate the precise amount or type of toxic byproduct that may have been produced in a given location or have been deposited there.

FIGURE 5. Detail of acute hazard map of London, 1915. Industrial hazards present in London at various time periods can be visualized at the city scale within the London HSDI by applying an IDW spatial interpolation to the IPPS-derived hazard factors appended to the London HSDI BE data. This image shows the distribution of industrial hazards across a large section of London in 1915. Image by author.

Applying a Weighted Spatial Interpolation

To create an interpolated surface representing the spatial distribution of industrial hazards at each time slice within the London HSDI, we first convert the building polygon data containing our IPPS-derived hazard factors into a point feature class within ArcGIS pro that replaces each building footprint polygon with a set of points corresponding to each vertex in the original building footprint polygon. This point feature class (still containing all building footprint attribute data) is converted into a raster where each pixel value corresponds to the hazard factor value present in the parent point feature class. We then conducted a spatial analysis of the raster data within ArcGIS Pro. Mapping the spatial distribution of soil pollution is often accomplished using spatial interpolation approaches [37]. We chose to use an inverse-distance weighting method

(IDW), as it has proven to be an appropriate choice for identifying industrial pollution hotspots [37, 38]. We generated the raster outputs at a 10-meter resolution using the IDW tool within ArcGIS Pro with a weighting power of 2. Given the large number of sample points generated from the building footprint data, the IDW function considered the nearest 500 neighboring points in order to calculate a final hazard value for each pixel in each output raster. We repeated this process for each of our four time slices. Each of the resulting acute hazard maps (Figure 5) represents the spatial distribution of the effects of industrial point-source pollution at a discrete time period. Each pollution source can be visualized in terms of location and severity based on the IPPS-derived hazard data, and the specific industrial sectors and/or industrial processes involved may be identified by querying the attributes in the spatially coextensive BE data.

The acute hazard maps are useful for studying historical industrial hazards within each of their discrete time frames based on industrial activities taking place at that moment in time. Because the London HSDI contains data from multiple time slices, we can use GIS-based spatial analysis tools to generate an interpolated surface representing the accumulation of industrial hazards over time, while maintaining the spatial linkages to all of the historical data previously collected. In order to do this, we used the Cell Statistics tool within ArcGIS Pro to sum the hazard factor values generated within each of our acute hazard maps. This process generates a 10-meter resolution output raster covering the entire study area whereby each pixel represents the sum of all of the predicted hazard factors in that location over time. This cumulative hazard map thus represents the hazard potential resident in the contemporary or postindustrial urban landscape of London. Within this map, “hotspots” represent a more complex interaction of discrete industrial activities and changes in land use over time.

2.5 CREATING A “GROUND TRUTH” REMEDIATION DATASET

In order to evaluate the predictive power of the cumulative hazard map, we compared it against areas in London where soil testing has revealed sufficient levels of pollution to require soil and water testing and /or remediation prior to redevelopment. We acquired this data from two primary sources. The first is a list of brownfields and

contaminated sites made available by the province of Ontario's Ministry of the Environment, Conservation, and Parks [39]. This publicly-available information identifies the location of each property (both street address and lat/long coordinates), the property owners, the results of soil testing undertaken at each property, and whether the property required remediation. To prepare this data for use with the London HSDI, the geographic coordinates for each property were transcribed into a spreadsheet along with the address and whether or not the property required remediation. We then imported this data into ArcGIS Pro and converted it into a point feature class using the geographic coordinates provided. Once within this format the data was applied to polygons representing current London parcels.

The municipal government of the city of London provided the second set of remediation data. Due to liability concerns, a condition of our access to spatial data locating remediated properties was that it had to be degraded in spatial accuracy and all specific information identifying the owners of the property redacted. This remediation data is therefore also represented at the parcel level rather than at the building footprint level or by precise geographic locations where soil samples were collected. This second remediation dataset consists of a list of those privately-owned properties (identified by address) that have taken advantage of the City of London's Brownfield Incentive Program to partially fund soil and water testing and remediation of contaminated properties. These addresses were matched with appropriate modern parcel data with the London HSDI and merged with the provincial brownfield data. Altogether, these two datasets provided us with parcel-level spatial data representing 46 sites that underwent soil and water pollution testing. Of these, 35 required remediation, and 11 did not require remediation. Together this data serves as a means of ground-truthing the hotspots generated by our cumulative hazard map against real-world pollution test results.

FIGURE 6. By summing the acute hazards recorded in multiple time periods, the London HSDI can be used to visualize the estimated accumulation of industrial hazards on a postindustrial landscape and highlight higher-risk hotspots. This predictive model can then be checked against real-world pollution testing data. In the image above, contaminated properties are outlined in black, while properties that were tested but did not contain contamination are outlined in blue. Image by author.

3. RESULTS

After overlaying the tested parcels on our cumulative hazard map, we find a substantial correlation between locations where the hazard model predicted an elevated hazard factor and tested sites that required remediation (Figure 6). Of the 46 sites tested for pollution, the hazard model predicted a high hazard factor for 22 out of 35 (63%) of the tested sites that required remediation. The model predicted a low hazard factor for 8 out of the 11 (73%) tested sites that did not require remediation. While our hazard model remains in development, these initial results illustrate several important advantages of our HSDI-based model compared with previous attempts to map the legacies of industry

in urban areas. First, the temporal depth of the London HSDI bookends the city's era of industrial activity, thus giving us a more complete picture of the changing industrial landscape than previous models with less comprehensive temporal coverage. Second, due to its construction at the building footprint and sub-building scale rather than the parcel scale allows us to model industrial activity within a parcel, bringing a new level of detail to the modeling of historical industrial landscape. This permits a far more sophisticated contextualization of industrial activity that begins to approach the micro scales that archaeologists seek to reconstruct. Third, and finally, our model is capable of illustrating the historical process of industrial "churning" in more detail due to the amount of information carried within the London HSDI's BE data; small-scale operations such as blacksmith shops and non-industrial hazard point sources such as auto service stations are factored into the London HSDI's hazard model. The addition of these small-scale, temporally more ephemeral and non-industrial sites may generate hazard hotspots in the cumulative model that would have been overlooked in models based on a narrower set of industrial hazard sources.

The higher level of spatiotemporal detail achieved within the London HSDI underscores the daunting complexity of the phenomena we are attempting to map. Three phenomena in particular underlie this complexity: the sheer number of industrial activities taking place in the city, their complex spatial patterning, and the changing use of the landscape over time. Hundreds, later thousands, of industrial operations are scattered throughout London. Each of these operations are composed of a series of micro-scale activities, each with its own features and each producing distinct byproducts; each of these thousands of unique industrial loci must be taken into account when attempting to model an urban industrial landscape. Second, the distribution pattern of industrial sites is important. While they tend to cluster in districts, some are relatively isolated and even districts may vary widely from one another in their composition and context. Understanding the spatial patterning of this landscape requires us to consider not only the numerous industrial operations, but also their context within the natural landscape, non-industrial portions of the built environment, and of course the social environment occupying this physical landscape. Finally, land use may change rapidly in

an industrial city, continually altering the context of industrial operations, which themselves also appear and disappear, or expand and contract as time passes; succeeding land uses may or may not be industrial.

Currently, identifying industrial hazards within this landscape is pursued piecemeal and on a small scale - contemporary environmental testing for persistent pollution covers only a tiny fraction of the city's total area. This is done on a site-by-site basis prior to redevelopment and is not part of a larger program of mapping the presence of historical hazards in the city as a whole. A geographically comprehensive program of soil and water testing in London is clearly not practicable, making any useful proxy for testing – particularly one that can operate at large as well as fine scales - a valuable addition to real-world testing efforts. Our predictive model helps fill this gap in knowledge. The model has the benefit of mapping industrial point-source hazards at a very high spatial resolution using the historical record, while retaining a city-scale frame of reference. The high level of detail achieved by historical FIPs is mirrored in the BE data of the London HSDI, so that individual activity areas can be linked to hazard factors that are appropriate for their corresponding industrial sector. The calculation of hazards at the sub-building level brings additional nuance to the interpolation of industrial hazards where no testing data, or only limited testing data, may be available.

3.1 ONGOING CHALLENGES AND FUTURE DEVELOPMENT OF THE MODEL

In cases where the predicted values did not correlate with the pollution levels in tested sites, our model predicted a low hazard value for 13 of the 35 sites that required remediation, and a high hazard value for 3 of the 11 sites that did not require remediation. This indicates that the model tends to underestimate the real-world hazard factor. Several factors may account for this. First, as previously mentioned, our decision to use the total lower bound pollution estimates within the IPPS results in predicted hazard factors that are likely to be conservative. Second, while the spatial coverage for each time slice within the London HSDI is fairly comprehensive within the study area, the temporal coverage is limited by the number of years for which FIPs were produced. While new time slices with city-scale coverage is costly and time-consuming, the spatial

coverage of the London HSDI's hazard model will improve in the future as further historical cartography is gradually incorporated. A secondary consideration in the use of FIPs is the fact that they were amended over time to show changes in the built environment [40]; major alterations or demolition events are reflected in these amendments, possibly erasing records of earlier industrial activities. Together, these gaps in the built environment record may conceal industrial operations that were active during periods not covered by the historical cartography. Third, and finally, the hazard model does not take account of vernacular, undocumented, or illegal dumping of waste. These dumping episodes may result in in real-world testing results indicating high levels of pollution where no formal industrial activity took place. Of the 3 sites where the model predicted higher hazard values in locations where real-world testing did not find elevated levels of pollution, 2 were situated close to hotspots with higher hazard factors. These may represent false positives that could be eliminated through further adjustments to the IDW parameters, such as the power factor and number of neighboring points considered.

Because our hazard model is based on building footprints (with the exception of the modern acute hazard map, which is parcel-based), the model is focused on point sources of pollution generated in historically recorded building footprints and storage areas (such as chemical tanks or coal storage bins). This approach does not consider pollution point sources generated by the undocumented dumping of toxic byproducts elsewhere on an industrial site. The smoothing effect of the IDW interpolation mitigates this to a degree, but it is likely that the acute and cumulative maps underestimate local hazard factors in areas where on-site dumping occurred.

As we iteratively develop the London HSDI, we plan to address these limitations using three approaches that will expand the spatial and temporal breadth of the model, incorporate new forms of data and identify improved analysis techniques. First, ongoing expansion of the HSDI to incorporate additional historical maps and new archival data (including additional company records, blueprints, and work diaries) will continue to fill gaps in spatial and temporal coverage within the London HSDI. Second, we will continue to add real-world environmental testing data to the model as it is generated, to

ground truth the predictive model and also to serve as a spatial representation of documented contemporary industrial hazards. Additionally, we can link groups of pollutants identified by environmental testing to groups of industrial operations that occupied a given location through time as represented in the HSDI - narrowing down the potential source of recorded pollution to specific historical industrial operations or even specific activity areas. Finally, continual experimentation with a variety of differing spatial analysis approaches, such as those discussed in Xie et al. will lead to improvements in the hazard model in future iterations of this analysis.

4. DISCUSSION

The results of this investigation demonstrate that the historical record continues to offer important new insights on the legacies of long-term industrial activity when examined from a new perspective, and that this new perspective can be beneficial to archaeologists. When digitized and manipulated in the form of spatialized historical big data within an HSDI, seemingly familiar sources such as fire insurance plans and business directories can be visualized and analyzed in ways their creators could not possibly have envisioned, providing us with new insights into the formation processes underlying the postindustrial landscape and the hazards it conceals. The industrial hazard model within the London HSDI improves upon previous research [18], [19], [22] that investigated the ways in which different scales, types, and durations of industrial activity produce vastly different material legacies, and how changes in land use concealed hidden risks. Just as our model is the result of an interdisciplinary approach to studying the postindustrial city, its value can be understood from multiple disciplinary perspectives including archaeology, historical geography and historical GIS, and the spatial humanities. Our methodology moves us towards a transdisciplinary approach to studying the postindustrial city that links not only scholars and researchers from different disciplines, but also potentially the public and municipal decisionmakers as well.

By incorporating the IPPS within the London HSDI, we extend the predictive value of the IPPS to historical archaeology research. This demonstrates that big data-based HGIS and HSDI concepts originally developed by geographers can be combined with the basic elements of predictive modeling to create a novel type of GIS-based longitudinal industrial hazard model. The London HSDI may serve archaeologists as a predictive model for site prospection in several ways. For cultural resource managers, this could serve as a starting point when evaluating the historical significance of a property prior to redevelopment or for nomination to heritage status, such as municipal or provincial heritage registers in London, or the National Register of Historic places in the USA. Academic researchers could use the London HSDI as a predictive model in other ways, for example to identify similar sites suitable for comparative analysis prior to committing to resources to field work. In both cases, the model may also serve to alert archaeologists to pollution that may present a hazard to the archaeologists themselves, reducing the chance that fieldworkers suffer accidental exposures to hazardous materials. This study also underscores the need for archaeologists working in postindustrial urban contexts to consider industrial byproducts as archaeological evidence in its own right as well as a hazard, evidence that may contribute to better understandings of the behaviors of both historical and contemporary urban dwellers. Our application of the HSDI to archaeology demonstrates one innovative way historical archaeologists may use a familiar tool, GIS, to address issues of scale in archaeological research by contextualizing the lives of past people at new levels of detail within a sophisticated, spatiotemporal, city-scale model of industrial hazard exposure. The adoption of such infrastructures as a new way to access the historical record represents a worthy contribution by historical archaeologists to broader “grand challenges” in digital archaeology [41-43].

While the focus of the current investigation is on an archaeological application of the London HSDI, the HSDI itself represents a substantial evolution in historical GIS approaches. In using it as the basis for our investigation we augment HGIS research currently being developed by historical geographers, historical demographers, historians and others by incorporating a historical archaeology frame of reference. This more

advanced form of HGIS, incorporating archaeological approaches, is a useful step towards building deep maps, a rapidly growing area of interest within the spatial humanities [44]. The application of archaeological knowledge to deep mapping and the spatial humanities shows a great deal of promise but remains in its infancy as an area of research [23, 45]. The current project pushes this promising collaboration forward.

We developed the London HSDI's industrial hazard model not only for its research potential, but also with an eye towards broader consumption. Government and nonprofit cultural heritage management professionals could use the HSDI to contextualize properties within "lost" neighborhoods and districts when evaluating historical significance of properties, and the HSDI itself could easily incorporate heritage registry or listing data. Municipalities increasingly rely on their GIS in order to help manage a wide range of municipal demand including property management, development, infrastructure, transportation, sanitation, and law enforcement. What these GIS currently lack is temporal depth. The BE data, SE data, and industrial hazard model within the London HSDI can help provide this context. Being able to survey the historical built environment and the accumulation of industrial hazards in London from the city-scale to the sub-building scale at once can help guide planners, developers, and other municipal decisionmakers at the early stages of any project involving ground disturbance, potentially avoiding costly delays or inadvertent exposure of historical hazards.

While all of these individual benefits are valuable, we see the most crucial benefit of the London HSDI to be its potential for collaboration and communication between archaeologists and researchers, municipal decision makers, and the public. While the construction of an HSDI is time and resource-intensive [46, 47], the HSDI can serve as a common space-time platform where users of archaeological, historical, and municipal spatial data may connect, share information, and better recognize each other's needs, approaches, and challenges. Ideally, the HSDI can serve as a communal decision-making tool facilitating community heritage-making, archaeologically sensitive urban redevelopment and city management [48]. While the HSDI is an approach to

modeling the past, its most important application lies in addressing the needs of the present: understanding and confronting the industrial legacies of the urban rustbelt.

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HERITAGE MAKING THROUGH COMMUNITY ARCHAEOLOGY AND THE SPATIAL HUMANITIES

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ABSTRACT

The archaeology of postindustrial landscapes is still a relatively undeveloped area of study. The impact of economic, social, and urban development efforts on both tangible and intangible heritage complicate our attempts to understand these places. Despite this, the practice of integrating heritage practice and promotion into the regeneration of a postindustrial landscape continues to grow in popularity. Within this context, genuine public-expert collaboration is the most effective means towards developing a sustainable compromise between protecting community heritage values and fostering economic development and regeneration. In this paper we have identified three broad categories of challenges for studying and promoting heritage in postindustrial regions- physical, social, and political - and propose a digital data-focused geospatial approach to how community archaeologists and heritage specialists can potentially overcome these challenges. We argue that coupling this data and technology with a robust research agenda and public programming can serve as a crucial two-way link, enabling long-term sustainable heritage-promotion and protection in post-industrial communities.

KEYWORDS:

Postindustrial, Heritage, Archaeology, Spatial Humanities, GIS

The Keweenaw Time Traveler (KeTT) Project is an interdisciplinary project that applies digital, spatial approaches to the study of a former copper mining region in northern Michigan. While the KeTT project supports research within the academy from a variety of disciplinary perspectives, the KeTT also focuses on fostering citizen science and community heritage-making. The present study identifies several key challenges the KeTT team faced in undertaking this work within a postindustrial community and reflects on the lessons the experience can offer practitioners of community heritage and archaeology.

1. THE CHALLENGES OF POSTINDUSTRIAL HERITAGE LANDSCAPES

Working within landscapes that have experienced the processes of deindustrialization presents archaeologists and heritage professionals with a distinct set of challenges. The formal study of deindustrialization is a relatively recent phenomenon (High 2013), and by consequence the process of understanding the heritage of postindustrial places remains in its early stages. Heritage itself is often seen as a tool for economic regeneration, and while this can be problematic (Waterton and González-Rodríguez 2015), the concept of integrating heritage making, heritage conservation and post-industrial redevelopment clearly has potential (Cizler, Pizzera, and Fischer 2014). Within this context, we have identified three broad categories of challenges - *physical*, *social*, and *political* - that complicate postindustrial heritage landscapes.

In its most straightforward *physical* sense, deindustrialization's legacy has been one of abandonment and ruination, as large swathes of manufacturing complexes left idle for decades have suffered from physical neglect and vandalism, and depopulation has left many neighborhoods empty (Mah 2012). Industrial landscapes are composed of a complex, large-scale, interrelated series of sites representing all of the stages of production and the transportation networks that linked them together, along with their associated communities (Palmer and Neaverson 1998; Stuart 2012). Processes of physical ruination are geographically uneven, resulting in a postindustrial landscape

where this historic physical fabric is in some places prominent, in others visible only to the archaeologist. Despite their impressive scale, industrial ruins are also fragile (Tempel 2012). This makes it difficult for experts, professionals, and the public alike to see physical contexts that may be crucial to the local heritage.

Postindustrial landscapes face increasing physical development pressures and developing a mutually beneficial balance between heritage conservation and development planning has become increasingly important (Barber, 2013; Bertacchini and Segre 2016; Appendino, 2017). Environmental sustainability considerations are becoming increasingly central to planning and development efforts, and the treatment of tangible heritage must also fit within this paradigm (Balliana et al., 2016; Nocca 2017). Balancing all of these needs will often lead to difficult choices, and it is important that all parties involved in this process are able to effectively contextualize the physical heritage landscape. How can the various visible fragments of the historical landscape be effectively articulated with each other? How do we advocate for heritage in ways that preserve these contexts while meeting pressing economic and environmental sustainability needs? Stabilizing and clearly connecting physically extant portions of the postindustrial heritage landscape with “lost” elements or less visible archaeological remains represents an important *physical* challenge.

A key focus of deindustrialization scholarship has been its *social* consequences, the “economic and political ruination” suffered by tens of millions of people, the majority of them working class, as a result of the collapse of manufacturing industries (High, MacKinnon, and Prichard 2017 p. 4). While the social networks of postindustrial communities have often proven to be remarkably resilient, the transnational movements of capital that characterize today’s global economy have left these communities behind (High, MacKinnon, and Perchard 2017). Attempts to remedy this situation in postindustrial places have been met with mixed success because the benefits of recovery are distributed unequally (Mallach 2018): while postindustrial *places* may appear to recover, all too often those industrial *communities* that suffered most directly when the factories closed do not (High, MacKinnon, and Perchard 2017). Since heritage landscapes are composed of a combination of interconnected tangible and intangible

components, the loss of these industrial communities as a byproduct of redevelopment is just as destructive to the heritage landscape as any physical damage to its historic fabric. A second challenge we face, therefore, is to effectively populate our physical representations of the landscape, past and present, with their attendant *social* networks in order help maintain the visibility and viability of the latter.

Finally, we identify as *political*, the challenges associated with fostering genuine multi-vocal heritage making within postindustrial heritage landscapes. We are keenly aware of the injustices and inequalities inherent in single, expert-generated heritage narratives that have been exposed by a growing body of critical heritage scholarship (Meskell 2015; Baird 2017). Any heritage landscape formed even partially by processes of deindustrialization is necessarily constituted from a tangle of heritage values that are “dissonant” (Tunbridge and Ashworth, 1996) and multivocal. It is our task to support this understanding of heritage to the greatest extent possible. How can we, as the “experts”, make space for this dynamic and conflicting collective of memories (Belford 2015; Orange, 2015) that are a crucial component of the postindustrial landscape?

Expert-led community engagement, however well intentioned, does not necessarily alter the power balance of a single, dominant heritage narrative (Smith 2006), and so we must be constantly reflexive in evaluating our project’s ability to support multivocality.

In the foregoing discussion we have characterized postindustrial heritage landscapes and three challenges they face in a general sense. It is, however, important to recognize the localized nature of deindustrialization. Each deindustrializing community or region has experienced this process in specific ways according to local historical sociopolitical dynamics, the type of industrial base each community was built upon, and the success (or failure) of efforts to transition to a postindustrial economy (Berger and Wicke 2017). With this in mind, we present a brief sketch of the Copper Country, the postindustrial heritage landscape that serves as our case study.

2. THE COPPER COUNTRY AS A POSTINDUSTRIAL HERITAGE LANDSCAPE

Upper Michigan's Copper Country takes its name from the unusually pure copper that is found there (Krause 1992). Native Americans in the Upper Great Lakes discovered and made use of these copper deposits for millennia and first established the region's reputation as a source of pure copper. Native groups revealed these copper sources to European explorers as early as the 17th century (CITE); subsequent Euro-American copper exploration often relied on native knowledge, both ancient and contemporary, to locate the deposits that became the focus of historical mining activities (CITE). Beginning in the 1830s, Ojibwe bands living in the upper Great lakes signed treaties ceding huge tracts of land in present-day Michigan, Wisconsin, and Minnesota to the United States, and moved to reservations established by those treaties (Satz and Apfelbeck 1991; GLIFWC 2018). By the 1840s, Euro-American mineral exploration in the region initiated the first in a series of copper mining booms. The region grew to become a nationally significant source of copper during the second half of the nineteenth century, just as large-scale electrification projects in the United States made this already culturally and economically significant mineral indispensable (Lankton 1991). This very long association with copper extraction remains strongly evident in both the physical and cultural landscapes to this day, more than half a century after the cessation of the last large-scale mining operation in the area. (Lankton 2010). (*Figure 1*)

Today, the Copper Country sits within Keweenaw, Houghton, and portions of Baraga and Ontonagon counties in Michigan's Upper Peninsula (*Figure 2*). This encompasses several substantial towns and numerous smaller villages set within over 2,000 square miles of rural, mostly forested land. The Copper Country is a postindustrial heritage landscape with vast physical remains of mining sites, both large and small, ancient and more recent; among the most recognizable of these features are a few preserved shaft rock houses standing over mineshafts, railroad rights-of-way (most of which have been converted into off-road vehicle trails), the ruins of mining buildings

such as engine and boiler houses, mills, smelters, and also waste rock and mill tailings piles.

FIGURE 1. The Copper Country's postindustrial heritage landscape is composed of a mixture of extant and "missing" physical and cultural elements, both contemporary and historic. (Illustration: Lynette Webber / National Park Service)

FIGURE 2. The Copper Country encompasses the shaded portion of the Keweenaw Peninsula and is located on the southern shores of Lake Superior in Upper Michigan. (Illustration: Dan Trepal)

Aside from the physical remains, the heritage landscape also manifests itself in the descendant communities of immigrant groups, such as the Scandinavians and French-Canadians, who established villages with toponyms that reflect their cultural identities: Frenchtown, Swedetown, Toivola, and Lac Labelle, for example. These settlements are surrounded by the remains of the landscape-scale industrial systems, processes, and social phenomena that led to their creation and drove their subsequent evolution (Arnold and Lafreniere 2017). The end of the copper boom also led to steady depopulation, economic stagnation, and poverty that remain very much visible in the regions' towns and countryside (Winkler et al. 2016).

The byproducts of past industrial activity and their ecological impacts shape of this postindustrial landscape in crucial ways. Toxins leaching from waste rock, mill waste, and smelters represent an ongoing threat to the local ecology (Kerfoot et al. 1999; Morin 2013). Huge, shifting deposits of stamp sands (waste rock ground into a form of sand during the milling of copper ore) previously dumped into inland lakes and Lake Superior itself can bury fish spawning grounds and block navigation channels (Yousef et al. 2013). The postindustrial community is burdened with the persistent costs of the historic mining boom without sharing in much, if any, of the wealth it generated (Morin 2013).

The Copper Country's past as a nationally significant extractive landscape, coupled with its vast extant archaeological remains, serves as a focal point of contemporary heritage making as evidenced by the creation of the Keweenaw National Historical Park in 1994, a national park that focuses on interpreting the historical copper mining era of the region. However, the Copper Country is also cast as a place of great natural beauty, and the local tourist economy - a crucial local source of income and employment - necessarily is shared between mining heritage and outdoor recreation-focused components (Regenold 2007; Lankton 2010). As a result, this landscape cannot be neatly categorized as drawing its significance from primarily natural or cultural, tangible or intangible elements. During the mining era the copper country experienced seismic social events, including the miner's strike of 1913 and related Italian Hall

disaster, a deadly stampede that occurred at a Christmas party attended by striking miners and their families (Lankton 1991). Events surrounding the strike remain disputed subjects within the community today, reinforcing the constituted nature of this heritage landscape. Finally, while the community's links to this extractive past are both strong and personal, their own livelihoods also rely substantially on the successful marketing of this heritage to visitors from elsewhere (Liesch 2016).

SPATIAL APPROACHES TO HERITAGE MAKING

The Copper Country, therefore, is a complex postindustrial archaeological and heritage landscape, with strong community ties to its historic role as an important copper mining district (Arnold, Lafreniere, and Scarlett 2019). Facing the physical, social, and political, challenges inherent in studying such a landscape, we have initiated an interdisciplinary project that is focused on the application of digital, spatial methods to collaborative knowledge production and heritage making among academics, heritage professionals, and the public at-large. We call this the Keweenaw Time Traveler (KeTT) project. For the KeTT team – historians, archaeologists, geographers, GIS specialists, and computer scientists conducting research of and within the Copper Country – our public digital, spatial heritage platform serves as a virtual space for heritage making (Scarlett et al. 2018). These sophisticated digital representations serve as tools of collaboration among the broad public, local heritage professionals, and academic researchers in the production of a multifaceted, dynamic understanding of the Copper Country as a postindustrial heritage landscape. The project began as a series of scoping meetings with community partners such as the National Historical Park, other local heritage organizations, libraries, and museums to form a partnership for sharing historical archival material, pooling public outreach resources, and provide public exposure for future KeTT products. The KeTT team then held nine meetings, based on the urban design charrette model, with a broad demographic of community members to learn about what community members would like to see in a web-based interactive map of the historical environments in the region (Lafreniere et al. 2019). During the charrettes the KeTT team and members of the public tested and critiqued early

prototypes of the KeTT web applications. The charrettes served as a space for the collaborative design of a digital interface that is accessible and focused the design team on content that represents the community's heritage values (Scarlett et al. 2018; Lafreniere et al. 2019). By iteratively repeating this charrette-based model for development of the project, we shift our role towards participating in the collective management of change in our heritage landscape rather than serving merely as experts curating a fixed, monolithic heritage narrative. In order to succeed, this interaction must be accomplished in ways that not only benefit the community but are also substantially driven by it.

The application of digital, spatial methods to the challenge of achieving genuinely collaborative community-engaged research is still in its early stages. Crowdsourcing has become a popular means for developing a cooperative relationship between cultural heritage experts and the public; such relationships typically revolve around the conversion of large bodies of historical data from one format to another through publicly accessible digital tools (Aucott, Southall, and Ekinsmyth 2019; Ridge 2014; Southall and Lafreniere 2019). The interdisciplinary field of historical GIS (HGIS) has demonstrated the possibility of visualizing and analyzing the past from new, spatially-focused perspectives that can challenge current understandings of the past (Gregory, Debats, and Lafreniere 2018; Olson and Thornton 2011, Knowles, Cole, and Giordano 2014). HGIS scholars have coupled this visual, spatial approach with the crowdsourcing concept in innovative ways such as the georeferencing of maps (Vershbow 2013), and transcribing place names from historical cartography (Southall et al. 2017). Some of these projects, such as the New York Public Library's Building Inspector (<https://buildinginspector.nypl.org>), adopt a game-like interface that additively streamlines crowdsourcing tasks relating to digitizing historical maps such as checking the accuracy of digitized historical building footprints, transcribing text, and recording color-coded building classifications.

Archaeologists also have begun arguing for new and wider applications of spatial technologies such as GIS, as well as the use of spatial storytelling and augmented reality approaches developed within the digital humanities (González-Tennant 2016; Earley-

Spadoni 2017). Gonzalez-Tennant adopted a collaborative, digitally augmented approach to his own archaeological research centering around the destruction of the African-American community of Rosewood, Florida, in the 1920s and the resulting complexities of the archaeology of racial violence and social justice (González-Tennant 2018). His web-accessible Virtual Rosewood Project (<http://www.virtualrosewood.com>) showcases the collaborative potential of digital technologies that can be implemented so as to “avoid depoliticizing complex histories of disenfranchisement while eliciting poignant and critical reflections from the public” (González-Tennant 2018, p. 149). The project website couples an interactive 3D digital reconstruction of the town of Rosewood with a traditional historical narrative, transcripts of oral histories from community members, and a digital documentary.

Earley-Spadoni (2017) argues that the discipline of archaeology, long familiar with GIS-based mapping and spatial analysis, can benefit from digitally-based deep mapping, spatial storytelling, and data visualization approaches developed within the digital humanities. Unlike existing implementations of spatial technologies such as GIS in archaeology, these promote open-ended data exploration rather than presenting expert-produced representations or results of analyses; this represents an excellent opportunity for more effective public engagement through collaborative data exploration.

One of the major goals of the Keweenaw Time Traveler project is effective collaboration with the public in heritage making. However, our subject, the Copper Country, covers a much wider geographic, temporal, and thematic expanse than most spatial projects and thus requires a different methodological approach in how it represents the past. For this we turn to HGIS and the spatial humanities and apply a series of digitally based approaches to create a publicly available digital platform. This platform is designed to help academics, professionals, and the public explore and define the Copper Country’s heritage landscape together, transparently incorporating widely differing forms of knowledge and leveraging the best features of each in a more inclusive, equitable, and effective heritage making process (Scarlett et al 2018; Lafreniere et al. 2019). Our approach, outlined in the following section, takes the form of big-data based spatial

representations of past and present environments – in the Copper Country – that supports and links together in one collaborative digital environment several important activities. First, the KeTT supports both academic and public explorations of, and contributions to, our collective knowledge of the regions’ historical record and heritage. The KeTT also supports professional management of heritage resources. Finally, the KeTT can also serve as a resource for planners, municipal governments, local nonprofit organizations, and other groups interested in promoting the heritage of the Copper Country.

FIGURE 3. The CC-HSDI and Keweenaw Time Traveler each offer a specific set of potential benefits to academic researchers, professionals, municipalities, and the public. (Illustration: Dan Trepal)

3. CREATING A DIGITAL, SPATIAL INFRASTRUCTURE FOR UNDERSTANDING THE PAST

From a methodological perspective, the focus of our research has been on developing a digital infrastructure that supports a collaborate environment of researchers

(Figure 3), professionals, and the public to explore, visualize, manipulate, and analyze postindustrial heritage landscapes across spatio-temporal scales. We call this digital infrastructure a historical spatial data infrastructure (HSDI), and it consists of the hardware and software backend of our public KeTT project web interface. An HSDI is a collaborative digital infrastructure for managing knowledge about a particular space and time, ensuring data interoperability, scalability, common data standards, reliability, and accessibility (Trepal, Lafreniere and Gilliland forthcoming; Lafreniere et al. forthcoming).

Our implementation of the Copper Country HSDI (CC-HSDI) adopts a multi-stage approach first developed by Lafreniere and Gilliland (2015) wherein discrete built and social environments or stages are each constructed out of a series of geodatabases; the data are then connected through a complex series of spatial and tabular linkages that adhere to established standards. Within the CC-HSDI, these data are stored in linked, relational spatial databases known as enterprise geodatabases that are easily accessible via web apps, making the content accessible to, and even editable by, the public (Lafreniere et al. 2019). The CC-HSDI, therefore, is a general-purpose, interdisciplinary infrastructure for the study of the past within the Copper Country. The data in the built and social stages are based largely on the historical record, but stages focusing on the geological and archaeological records have been conceptualized and will be added to future iterations of the CC-HSDI (Trepal, Lafreniere, and Gilliland forthcoming). The CC-HSDI project covers a hundred-year period from ~1850 to 1950.

A brief overview of the structure and features of the CC-HSDI sets the stage for a discussion of the value of its application. The CC-HSDI is composed of two stages, the built environment (BE) stage and the social environment (SE) stage, both subject to augmentation. The BE stage is constructed by scanning and georeferencing historical maps and fire insurance plans. Each feature on the maps and plans, such as building footprints, transportation networks, and industrial systems are digitized into the CC-HSDI which allows the maps to not only represent historical space but can be used to capture information about the BE, link to other spatial data, and serve as the foundation

of 3D recreations of industrial communities (Arnold and Lafreniere 2017). As of this writing, over 116,000 footprints have been digitized and civic addresses, number of stories, built form, and other building features have been recorded for nearly every ten years from 1890-1950.

The social environment (SE) stage forms the second key component of the CC-HSDI and consists of a big dataset – approximately 6.9 million pieces of data from over 300,000 individual records thus far - of historical demographic data primarily drawn from four types of historical sources: city directories, the full-count decennial census, mining company employee record cards, and school records. (*Table 1*) We have geocoded these tabular records using a semi-automatic process in ArcGIS in which the addresses within the records are matched to custom historical geocoders built from extracted address information contained within the BE stage. The decennial census data are sourced from the individual level decennial census datasets made available by the Minnesota Population Center in its IPUMS project (Ruggles et al. 2017) and geocoded and linked to the buildings in the BE stage. The mining employee and school records are digitized and geocoded in a similar manner. Sources that lack civic address information are mapped via a semi-automated probabilistic record linkage procedure outlined by Lafreniere and Gilliland (2018). Collectively, these data reveal information on individuals including home and work addresses, occupation, marital status, household composition, whether they rent or own their home, religious affiliation, physical health, national origin, immigration status, languages spoken, and education level. An ongoing initiative involves record linking these sources together in space and time, resulting in a big data-based reconstruction of a century of information regarding family or kin networks, work networks, religious communities, and schoolmates within the Copper Country's broader population. It will allow for spatial-temporal analysis and recreation of complex social processes such as immigration, segregation, social mobility, and the social effects of deindustrialization and job loss. The CC-HSDI already has been used for heritage interpretation and management (Arnold and Lafreniere 2017; 2018, Arnold, Lafreniere, and Scarlett 2019), data-driven history education (Scarlett et al. forthcoming), and citizen science (Lafreniere et al. forthcoming). A more detailed

technical description of the creation of the CC-HSDI can be found in Trepal, Lafreniere, and Gilliland (forthcoming).

Through the complex spatial and tabular interlinkages across the CC-HSDI dataset we can flexibly visualize and explore past environments within the Copper Country in a variety of ways. The Keweenaw Time Traveler Project encompasses both the collaborative heritage making tools of the CC-HSDI and its application in the public realm. KeTT is an interdisciplinary public collaboration project, a key component of which is a set of web-based software tools that allow the public to access and explore the data and stories within the CC-HSDI. We have developed four web apps for the KeTT. Three of the apps (entitled “Document Building Material”, “Transcribe the Map”, and “Document Building Use”, and collectively referred to by the team as “builder apps”), are citizen science tools with game-like interfaces in which the public help add information to the built environment stage geodatabase through various map reading and transcription activities, the results of which are instantaneously available to all KeTT users (Lafreniere et al. forthcoming).

In this paper we focus on the fourth app, *the Explore app*. The Explore app allows the public and researchers without specialized knowledge of GIS to exploit the dense and complex spatial and tabular linkages among all of the built and social environment data within the CC-HSDI. The user selects a desired town and year from pull-down menus, and the Explore app automatically displays the appropriate set of historical map data for that place and time, within which the user can pan and zoom to explore. Transparency slider and spyglass tools allow users to peek through time from the historical maps to either a 1940s topographic map or a modern aerial image, allowing users to visualize change. A click on any building depicted on the historical map will call up all of the BE and SE stage data associated with that building for that year. Alternately, the user can search directly for addresses, people, and place names (*Figure 4*). Results include entries across space and time, allowing users to trace the movement of people within the Copper Country through the periods of rapid industrialization and deindustrialization.

FIGURE 4. The KeTT Explore App permits users to search for people and places in the past, either through text search or clicking on a location in the map. Search criteria and results are displayed in the panel to the left, while the map in the center dynamically adjusts to the relevant time and location. (Illustration: Keweenaw Time Traveler, Michigan Technological University)

The Explore app also includes a “share a story” function. (Figure 5) This feature allows users to contribute their own memories or heritage narratives to the CC-HSDI in the form of illustrated spatialized stories. Users select a location within the Explore app and contribute their content, which can be text along with photographs, audio, or video files. Users may also insert hyperlinks to additional online sources relating to their story. A Facebook plugin allows users to comment on the stories of other contributors and share their knowledge across social media. Stories are instantly searchable by keyword or by clicking its location in the interactive map interface. The “share a story” function contextualizes users’ memories and histories within the vast datasets and the CC-HSDI’s historical evidence-based reconstruction of past Copper Country environments. This story-sharing feature juxtaposes user-friendly access to rigorous historical record-based information with the sharing of multiple, possibly conflicting, publicly-held memories and identities with the past that collectively constitute the heritage of the Copper Country more broadly.

FIGURE 5. The Share a Story function allows KeTT users of the Explore App to select a location on a historical or contemporary map and input text, photos, videos, or audio. The submitted story then appears on the KeTT interface maps as clickable purple dots. Once clicked, the story is displayed in the pane on the left side of the screen. (Illustration: Keweenaw Time Traveler, Michigan Technological University)

4. THE KEWEENAW TIME TRAVELER AS A PLATFORM FOR MEETING THE CHALLENGES OF POSTINDUSTRIAL HERITAGE LANDSCAPES

By providing user-friendly access to big data-based explorations of complex past environments as discussed above, the Keweenaw Time Traveler supports collaborative heritage making activities that contribute to addressing the physical, social, and political challenges inherent in post-industrial communities.

PHYSICAL

The KeTT web interface contextualizes historical physical and social landscape features in today's spatial context using big historical data, providing the public with virtual access to places that either no longer exist or that may be too dangerous to physically explore. The KeTT makes linkages across time and space in order to visually

capture a changing landscape which then can be understood from a variety of perspectives and in combination with a wide variety of information. In other words, the KeTT provides the context in which experts, professionals, and the public can connect the natural with the cultural, the tangible with the intangible, and the explicit with the implicit. For instance, the precipitous drop in this region's population, from nearly 100,000 residents in the 1910s to about 45,000 in 2019 led to the loss of many domestic and commercial buildings. Remaining apartment buildings and storefronts can be visualized as part of a now-lost historical urban streetscape within the Explore App by using the transparency feature and available historical cartography layers, along with user-submitted historical photos of the buildings. Further, users can explore the social environments that once existed, such as ethnic ghettos, transient worker neighborhoods, or racially integrated community schools, through the spatialized social environment stage data.

KeTT team members have already employed this kind of contextualizing visualization activity at Michigan Technological University (MTU) within an archaeology field school and several undergraduate history courses. Students in these classes are given GPS-equipped iPads running ESRI's ArcGIS Explorer App loaded with CC-HSDI's BE and SE stage data used in the KeTT web software. Whether used in the context of an archaeological survey or excavation, or a walk through a neighborhood in a Copper Country town, the mobile devices allow students to simultaneously move through the visualized historical environments of the KeTT and the same space in the modern postindustrial landscape (Scarlett et al. forthcoming). This provides students with an immediate and powerful demonstration of the interplay of change and persistence (Arnold and Lafreniere 2017). This same tablet-based mobile employment of the CC-HSDI data also serves as a key component of the KeTT outreach program, one example of which is the team's participation in a National Park Service program called Copper TRACES.¹ The Keweenaw Time Traveler is one of over 20 stations visited by 400 fourth graders over three days in the former urban hub of Calumet. Using the iPads,

¹ <https://www.nps.gov/kewe/learn/education/classrooms/what-is-copper-traces.htm>

students explore the main commercial street in Calumet, learning about the businesses and structures that used to fill now-empty lots. This spatio-temporal orientation better contextualizes exhibits within the NPS visitor center displaying photographs and artifacts from missing components of the historical townscape, such as a large YMCA building that once stood in what is now the visitor center parking lot.

This kind of recreation of physical space is especially important for post-industrial heritage making. Industrial systems operate at enormous scales and incorporate transportation networks, extraction, production, and processing mechanisms stretching across ever-increasing regional, national, and global spaces. While many large-scale features of the historical industrial landscape remain, in the form of archaeological sites, ruins, and preserved or adaptively reused structures, these are still only fragments of the original industrial systems they supported. Moreover, even the more intact components may not easily be comprehended from one vantage point. These landscapes better communicate their meanings using flexibly scaled representations, and an HSDI. In the Copper Country, while some company structures have been preserved or repurposed, most were dismantled and salvaged by their corporate owners, leaving skeletal ruins, concrete footprints, partial walls, or overgrown brownfield sites. The academic researchers, community members, and visitors alike visualize these changes using both desktop and mobile applications within the KeTT Explore App. In order to balance heritage, sustainability, and development, it is important that all players have the opportunity to contextualize all of the components of the postindustrial landscape to support informed discussion and decision making. The KeTT represents a user-friendly and accessible digital platform to support this process.

SOCIAL

The physical remains of past industrial activity may be fragmentary, but they are still visible in the postindustrial landscape. The communities that occupied these landscapes, and their links to contemporary postindustrial communities, may not be as obvious. To address this, KeTT populates its recreated physical environments with historical communities through the process of geolocating demographic and qualitative

historical data sets. By exploring the interplay between its BE and SE stages, the KeTT helps users identify, visualize, and interpret social relationships at varying scales while retaining a high level of detail (Lafreniere and Gilliland 2015; 2018). Exploring people and social networks in context enhances both the accessibility and usefulness of the historical record to the public by digitally linking physically separated datasets and making them searchable, either through virtual spatial exploration or keyword searches. Representing a place of interest to many family researchers around North America, KeTT provides access to this data to those not able to make an in-person visit to the archival repositories in the region.

The social connections made possible through the KeTT have become increasingly evident in the project's public programming. During the summer of 2017, teams of undergraduate and graduate students took KeTT to 19 outdoor festivals and events that attracted locals as well as tourists (Scarlett et al. 2018). In virtually every form of public interaction, during both the design phase of the KeTT software and subsequent outreach activities, the most common questions were about an ancestor or specific person from the past. The rapid expansion of the Copper Country's population during the mining era was driven by the recruitment of immigrant labor. The initial wave of immigrants included Cornish, German, and French-Canadian migrants. Subsequent waves included Italian, Eastern European, and especially Finnish immigrant groups (Lankton 1991). Public interactions with the KeTT very often begin with the investigation of an immigrant ancestor's settlement in the Copper Country. Once they explained its capabilities, students inevitably heard questions about a person's family name or place with social connections. Comments on social media frequently offer stories about a specific family member or inquire about their places of residence or other relatives who used to live in the Keweenaw. Stories uploaded in the Explore App range from accounts of skirmishes that took place during the 1913 strike, to descriptions and photos of long-demolished commercial buildings, to memories shared by MTU alumni of university life in the past. While archaeologists or heritage professionals often focus their research at a particular site, most community members start with social connections. KeTT can thus serve as a way for researchers and the public to access the

same vast body of information about the past despite approaching it from different directions. Ultimately, KeTT makes the past social landscapes of the Copper Country more visible and highlights the links between past communities and our own.

FIGURE 6. The KeTT project has increasingly made use of GPS-enabled tablets to enhance public-expert collaborative activities. (Photo: Keweenaw Time Traveler, Michigan Technological University)

POLITICAL

In constructing the KeTT, we explicitly wished to avoid creating a single heritage narrative of the Copper Country and simply presenting it to the community or limiting community involvement to passive roles. We see the challenge of fostering recognizable multivocal and occasionally dissonant heritage making in our postindustrial landscape as a political challenge, and to meet it we must engage with the public in ways that are genuinely interactive. The KeTT interface, coupled with the team's outreach program, is explicitly designed to foster easy access to and interaction with a massive amount of historical spatial big data that supports expert research and public heritage making exist together within a multiply constituted digital representation of the postindustrial heritage landscape.

Achieving this requires a combination of the KeTT software and a series of complementary engagement activities (*Figure 6*). We draw on the research of community archaeologists and heritage scholars whose work has gained increased energy in the academy as scholars across multiple disciplines have embraced community-engaged scholarship (Waterton and Watson 2013; Richardson and Almansa-Sánchez 2015). We use a combination of HGIS approaches, social media, and in-person programming to implement a public practice that enables individuals with diverse life experiences to find “a way in” to exploring material and spatial remnants of the past that informs and generates new meanings for the present and future (Harner, Knapp, and Davis-Witherow 2017).

The Keweenaw Time Traveler and the CC-HSDI are aimed at fostering multivocality, yet the understanding among researchers that the social process of making material and spatial meaning is never uniform, nor universal, but rather multiple and overlapping can be opaque to the public (Massey 1994; Smith 2006). At public events, many community members ask how we ensure “accuracy” in the user contributed stories; our explanation that the past can be seen from a variety of differing perspectives often clashes with a public that received a history education based on problematic single-narrative models of history (McCully, 2012; Rosa, 2012). Though there is no simple answer to this challenge, Keweenaw Time Traveler contextualizes user-submitted stories within a vast body of historical records from the archives (which can themselves offer conflicting perspectives on the past), and this transparent juxtaposition is intended to help steep the public in the multiple voices and overlapping, occasionally conflicting narratives of the region’s past and present. In this context, contemporary heritage place making can be seen as part of a continuous cultural process that stretches back far into the region’s past. Rather than simply asserting to people that history is multivocal, we present people with a huge body of historical data containing thousands of personal histories, each with its own perspective, to which the contemporary community may add its own memories and stories. Exploring this digital space exposes the diversity of lived experience across time and space in the Copper Country to the public eye.

5. DISCUSSION: ONGOING CHALLENGES

Since its launch in the summer of 2016, the Keweenaw Time Traveler project has generated a substantial amount of interest in the community we intend to serve. Roughly 900 people have interacted with team members at various community events over the last two years. The team constructed two touchscreen kiosks running the KeTT web interface that allowed the public to learn to use the software and provide feedback to KeTT team members. KeTT's Facebook² and Twitter³ pages have generated spikes in traffic to the KeTT project site through topical posts relating to holidays, or the highlighting of specific places and stories, as well as notifying the community of upcoming public engagement activities. The public also contributed a substantial amount of data to the KeTT using the builder apps: 188,742 unique building material classifications, 93,109 unique building use classifications, 6,779 unique map transcriptions, and 630 stories shared. (*Figure 7*)

The KeTT has had a promising start since the public launch. As the project evolves, we remain focused on addressing ongoing challenges inherent in this kind of publicly engaged work. To begin with, we acknowledge that the project originated in the academy, among an interdisciplinary research team, rather than as a grassroots movement within the community. The first phase of our project was therefore focused on introducing the concept of PPHGIS, and its potential value to heritage-making, to the local community. The community response to this initial stage of the project has been overwhelmingly positive. Since then we have focused on growing this participation further with each new phase of the project, both in terms of sheer numbers of participants and connecting to new segments of the community.

² <https://www.facebook.com/KeweenawTimeTraveler>

³ <https://twitter.com/KeweenawHistory>

FIGURE 7. Public interactions with the Keweenaw Time Traveler Project. (Illustration: Keweenaw Time Traveler, Michigan Technological University)

Within this context, we must take seriously our responsibility to configure the project in ways that will facilitate the addition of stories from underrepresented groups and help redress the historical silencing of their experiences and viewpoints. Unless we can do this, we risk repeating the historical biases we know to be inherent in some of the historical data that constitutes the CC-HSDI. Local indigenous communities represent an obvious example of an underrepresented group whose identity forms an integral component of the broader Copper Country heritage landscape. Native Americans have lived in the Copper Country for thousands of years and, of course, are the first and longest-enduring users of copper in the region. They remain a significant segment of the regional population, and we acknowledge that the KeTT project has only just begun to address the historical biases in this area that form part of the regional authorized heritage discourse (Smith 2006, 4-5).

In the Copper Country, as with so many regions with colonial histories, the story involves significant displacement of indigenous communities. The three counties included in this HSDI incorporate land ceded in the Treaty of 1842, a fact acknowledged on the project's "About" page. The addition of resources that could help foreground Native American histories in the Keweenaw Time Traveler would highlight the legacies

of colonialization and the challenges of counteracting it. Unilateral efforts to make indigenous people more visible, however, bring risks. For example, if the 1845 General Land Office maps from the U.S. Government's first official survey of the region were made publicly available in the KeTT web apps, some locations denoted as sacred to Native American groups might be exposed to increased vandalism or threatened safety. Likewise, Native American pre-contact copper mining sites could become increased targets for looting if their locations were more easily identifiable - a challenge familiar to any archaeologist. While a map-based tool of this sort will never be entirely free of a European-derived view of land ownership, the voices of residents who tell Native American stories, and include Ojibwe perspectives, would contribute to the process of decolonizing the heritage of this region. The KeTT research team are currently working with MTU's directorship of university-indigenous community partnerships to foster collaboration with the indigenous community, and to explore ways native knowledge may be better incorporated into the CC-HSDI and KeTT.

A second ongoing challenge to the project is achieving effective engagement with a community that may not be receptive to government-funded projects led by experts without multi-generational roots in the community. As a project based at a state university, jump-started with funds from the National Endowment for the Humanities, KeTT remains situated within Western traditions that prioritize expert knowledge and sanctioned professional practice. In addition, few of the student team members have long-term ties to the community. When taking in a community's heritage values, heritage experts may sometimes overlook groups not typically described as disenfranchised, but who nevertheless identify as being misrepresented by broader society. In the Copper Country the identities of the groups who feel disenfranchised may differ somewhat from in other parts of the country. Among rural, white, postindustrial American communities suspicions and anger towards expert-led institutions is a real phenomenon (Hochschild 2017). Today, the population of the Copper Country is over 90% white and economically disadvantaged; while the Michigan Tech campus is more diverse than the community as a whole, the numbers are still small and tend to include

international scholars more than racially diverse Americans.⁴ In other words, many long-term Copper Country residents, whose participation is vital to the success of the KeTT, may consider themselves among the “forgotten” rural white working class whose intense feelings of disenfranchisement often are linked with the election of President Donald Trump in November 2016 (Davies 2018). Indeed, all three of the counties included in this project voted for Trump by more than 50% (Michigan Department of State 2016). Thus, a majority of our community possesses a political worldview that is associated with a distrust of intellectuals and the broader scientific community (Motta 2018). This places the KeTT team, as academic researchers without deep familial roots in the area, at risk of being cast as outsiders with an agenda that is at best not in tune with the needs of the local community, or at worst actively undermining it.

The KeTT project instigates locally focused conversations on heritage among groups who may not otherwise have meaningful relationships. For us, the ongoing challenge is to demonstrate that our federally funded, university-based HSDI and web apps serve the community in meaningful ways. Cooperatively exploring a mutual interest in place is a logical starting point for building mutual trust and recognition. To people having a conversation over the KeTT about favorite swimming holes, remembering old restaurants, or comparing their aging uncles’ old stories about the last days of the mines, the act of talking may not seem political. But in today’s increasingly polarized world, talking with neighbors to create place-based heritage may be among the most political acts of our age.

Our approach to these challenges is based upon iteratively applying our charrette based collaborative discussions with the community on the design and use of the KeTT software. We will continue to grow our user base through ongoing work with our

⁴ United States Census Quick Facts, Houghton County

(<https://www.census.gov/quickfacts/fact/table/houghtoncountymichigan/PST045216>) , Keweenaw County (<https://www.census.gov/quickfacts/fact/table/keweenawcountymichigan/PST045216>), Ontonagon County (<https://www.census.gov/quickfacts/fact/table/ontonagoncountymichigan/PST045216>). Accessed May 14, 2018.

community partner organizations and the KeTT team's continued presence on social media and in person at public festivals. Upcoming better user interface design and data visualization options resulting from our collaboration with the public and community partners will improve accessibility, promote more robust spatio-temporal queries, and overall user experience. The initial versions of the KeTT interface were designed by team members with modest experience in web design; our next proposed round of funding includes the recruitment of a dedicated interface design professional, with expertise in historical spatial data, who will substantially upgrade the interface and enhance both its usability and visual appeal.

6.CONCLUSION

Postindustrial heritage landscapes remain dauntingly complex stages for engagement among archaeologists, heritage scholars, and the public. Nevertheless, as recent critical scholarship on such places argues, it is in precisely within such challenging contexts that practical, effective engagement is most needed (Baird 2017). We believe that digital, participatory GIS-based approaches to collaboratively visualizing and exploring landscapes and communities, past and present, can support a broad-based interdisciplinary scholarship that is also truly engaged with local communities. We have focused on how our CC-HSDI can be used by archaeologists and heritage specialists, but our team also is composed of specialists in history, geography, GIS, and computer science. Collectively the team created something that is greater than the sum of its disciplinary parts. From the beginning our team has set the development of a meaningful collaborative relationship with the community as a crucial goal for the project. While we do face ongoing challenges in making and maintaining the KeTT as a truly community-driven heritage making digital environment, the initial results have been promising. Our approach can be summed up as a recursive process of asking the community what they need or want in a digital heritage platform; using our interdisciplinary expertise to develop those desired features while observing the best practices of our respective disciplines; and then returning to the community for feedback

and improvements. This is an open-ended process that will never be “finished” but will continue to respond to the evolving needs of the community and its heritage values.

The KeTT project is as much a way to link people and help them work collaboratively as it is a repository of information and a novel means to explore and visualize that information. In terms of identifying our role in the process of heritage making in the Copper Country fostering this collaboration is easily as important as academic knowledge production and methodological innovation. In our role as experts, we must make our expertise available in ways that serve the postindustrial communities we study, and to mitigate, rather than accelerate, those physical, social, and political forces that threaten them and the heritage landscape they occupy.

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CONCLUSION

Cleveland, Ohio, my childhood home, is a textbook example of a rustbelt city. Since the middle of the twentieth century, this gritty industrial city on the Cuyahoga River has existed in a state of transition from prosperous industrial powerhouse to a more diverse yet far more uncertain role as a regional service and financial center. As long as I can remember, I have been aware of the dissonance and the tensions of this process, tensions between the persistence of the past in Cleveland - communities, traditions, and, most starkly, the massive physical remains of industry, powerful in appearance yet crumbling and timeworn - and contemporary struggles over our identity and future as the costs and benefits of postindustrial “rebirth” are spread unequally across the city’s population. The persistence of the past, in physical and cultural form, has led me, by a circuitous route, to archaeology and heritage; to the study of people and things in the industrial era through an archaeological lens, and a desire to understand how humanity uses what we know (or what we think we know) about the past to establish build our identities and to decide where we should be headed. This dissertation represents the results of my own personal “turn” towards digital, spatial approaches to understanding the past, present, and future, and building connections that I hope will eventually be of use to a broader community. In that sense, I see this point as a beginning rather than an end.

It is clear that ‘digital archaeology’ is still very much in the process of being defined within the discipline (Averett, Gordon, and Counts 2016); at the same time, the assertion that “we are all digital archaeologists” (Morgan and Eve 2012) is essentially accurate. The *de facto*, often ad hoc adoption of digitally based approaches in archaeology has mirrored the pervasive absorption of the digital into human society as a whole, while the theoreticians, both within and without archaeology, breathlessly try to play catch-up.

As an archaeologist, I often find myself with my hands dirty, literally in the trenches, engaged with the material remains of the past. We touch what our predecessors touched, stand where they stood, and through a close study of their things we seek to

bring their world, their knowledge, and their points of view closer to us. This intimate relationship is the essence of archaeology and through it the discipline has made, and continues to make, essential contributions to our understanding of who we are as a species. This perspective, however, has its limits. We can only directly study the material we can physically access, and as we scale upwards – beyond intimate and day-to-day activities to networks and infrastructure that stretches across regions and even the entire planet – our relationship with our evidence become increasingly indirect. So it is with the postindustrial city. We can hold a button, a bone fragment, or a machine part in our hand; we can stand within a building ruin and experience its presence, even a ruin as large as the defunct Packard Plant in Detroit. Yet we cannot see, from an individual perspective, the totality of a city-scale network of past industrial activity, evolving through time, which can now only be assembled from seemingly innumerable fragments in the form of artifact assemblages, ruins, preserved buildings, and historical records.

Working on industrial scales requires appropriate modes of representation, and archaeologists have adapted to this need through a number of well-established representational approaches, each with their particular own strengths and weaknesses: diagrams, flow charts, cartography, artistic and physical reconstruction, for example. These have become integral to our work and yet we continue to search for new ways to represent and work with archaeological knowledge. The arrival of computers has led to an accelerating growth in the variety of ways we can represent the past; indeed, the accelerating penetration of the digital world into every aspect of modern society has left the discipline somewhat bewildered; a half century after archaeologists first used computers, “digital archaeology” is still seen as an emergent discipline, and its role remains a topic for discussion. As an archaeologist seeking to better represent change over time in industrial cities, I have been increasingly drawn to the affordances of digital archaeology. This dissertation represents the culmination of my efforts to identify digital, spatial approaches that help us better understand the archaeology of the postindustrial city and, in particular, those so-called rustbelt cities that have suffered the most from processes of deindustrialization.

Within this dissertation I have arrived at an approach, drawn from a variety of academic fields, that represents more than simply a new digital toolset, but rather a way of doing archaeology that is better suited to postindustrial places, and may serve as one component of a broader digital approach to studying the postindustrial city. The core of this approach revolves around the HSDI, a GIS-based digital infrastructure developed within historical GIS (Lafreniere and Gilliland, 2015; Lafreniere et al., 2019) that serves as a framework for representing the past across large spatio-temporal scales. In demonstrating the HSDI approach, I remain keenly aware of the hazards inherent in uncritical applications of digital technology to archaeology, whether that be a bias towards positivist interpretations (Connolly and Lake, 2006), or the consequences of a drift too far from the basic craft and experience of the archaeologist in the field (Caraher 2016; 2018). HSDIs, while they offer improved efficiency in certain tasks, are not designed for efficiency's sake. On the contrary, their purpose is to grow the context in which we work as much as possible by introducing new datasets, consider existing archaeological data from new perspectives, and to broaden our collaboration with other research, professionals, and communities. The unavoidable process of simplification inherent in the construction of digital models or digitized assemblages is not aimed at making archaeology simpler or more efficient, but rather at providing an accessible entrée into the iterative exploration of complex interactions between people, things, places and time from digitally-augmented perspectives.

The grand challenge to build digital infrastructures for archaeology is not aimed at making archaeological practice easier, faster, or cheaper, but to make things more rich and complex: to take more information and agents into account, to explore phenomena from a wider variety of perspectives and scales, and to identify more gaps in knowledge or weaknesses in our work that need to be acknowledged and addressed. The reflexivity and the pacing of the interpretative processes that I argue are necessary to use digital infrastructures in this way cannot be automated, packaged or commodified the way digital data collection, storage, and visualization technologies can. The HSDI is intended to be an augmentation to the existing craft of archaeological data collection and interpretation, not a replacement for it. Indeed, it is intended to show that the thoughtful

application of digital, spatial approaches to the study of the past is, and always should be, a craft as much as it is a science. Working from this perspective, I demonstrate the value of the HSDI to archaeology within this dissertation through three studies.

In my first study, I address the role of GIS within historical archaeology, and by implication, other archaeological subdisciplines that study more recent contexts, including urban archaeology, industrial archaeology, and contemporary archaeology. Taking on the call for a shift in how archaeologists use GIS from *tool* to *process*, (González-Tennant 2016), I explore the potential for linkage between historical archaeology and GIS-based research in the social sciences and humanities. In particular, I focus on how historical archaeologists can use an HSDI to expand the physical and temporal scales of archaeological research in the postindustrial rustbelt city of London, Ontario, and the postindustrial mining towns of the Copper Country in Upper Michigan. Historical archaeologists often rely heavily on the historical record as a framework for their research, but by and large still access it in basic ways, though discrete sets of paper archival documents or digitized copies viewed in traditional ways. I argue that GIS allows us to explore the historical records in far more productive ways. By using the HSDI, with its built and social environment stages, for the visualization and analysis of historical data, I demonstrated how historical archaeologists benefit from a much more flexible frame of reference for identifying patterns in the physical and social landscapes at widely varying scales, both in a moment and over a century of change time. This flexibility is made possible by the embrace of the historical record as big data within an appropriate infrastructure – the HSDI. Within this big data environment, archaeologists can adopt a hermeneutic approach, iteratively recontextualizing historical places for any one of a variety of purposes – locating new sites, comparing known sites, linking archaeological data to the historical record, representing sites in new ways, and sharing data with other researchers.

My second study focuses on how an HSDI can contribute to the study of the material legacies in the form of accumulated industrial hazards, an aspect of industrial cities that remains ever present in municipal management, politics, identity, and the daily lives of postindustrial urban communities. Starting from an HSDI-based historical

archaeology perspective as developed in my first study, I combine the big data capabilities of the London-based HSDI with the basic principles of archaeological predictive modeling to develop an industrial hazard model for London, Ontario. I visualized the accumulation of industrial hazards over time based on a highly detailed longitudinal spatial analysis of the historical record between 1888 and 2016. By checking the results against known pollution testing data I demonstrated that the historical record can indeed serve as a very useful adjunct to existing testing methods; The HSDI models industrial activity across the entire city and over 120 years. In addition to augmenting the affordances for archaeological and historical research as outlined in my first paper, this hazard model demonstrates how an HSDI can be used as a common platform for understanding a city through space and time. Municipal decision makers such as planners, environmental professionals and heritage managers can access and explore the same data archaeologists and other academic researchers are using, facilitating urban management that is more sensitive to the historical fabric and heritage values of a community.

In my third study, I examine the ways my proposed adoption of the HSDI by archaeologists could fit into the process of heritage making in Michigan's Copper Country. This study focuses on the ways in which the CC-HSDI can serve as a means for genuine collaboration with communities. The CC-HSDI helps address some of the physical, social, and political challenges to heritage making in economically depressed postindustrial communities by providing communities with a digital, spatial means of exploring a linked universe of community stories and expert knowledge while avoiding the common tendency for public engagement projects to develop a one-way expert-to-public flow of information. By allowing the public to explore CC-HSDI through a web interface and contribute spatialized stories to the HSDI itself, we can achieve a more organic mixing of expert and local knowledge that better represents the multiply constituted, sometimes dissonant threads that collectively form our heritage. In doing this, we also demonstrated how the HSDI is necessarily the result of interdisciplinary collaboration, a process from which each constituent group may greatly benefit. This is an early demonstration of how public archaeology stands to benefit from the incorporation

of HSDIs as a way to link archaeological sites and material remains to the historical record, community heritage values, and ultimately, to the contemporary world. On-site interactions with archaeology will always remain fundamental to the discipline, but HSDI-based models of archaeological landscapes can reach a far larger audience and can be more easily embedded in peoples' daily lives in the form of web and mobile apps that can be used to link community-based archaeology to important contemporary issues such as economic inequality, redevelopment, and environmental justice. Achieving this visibility is crucial to the survival of the discipline, and on-site public archaeology alone is not going to be sufficient.

FUTURE DIRECTIONS

The crucial test of the HSDI concept is therefore whether it will be taken up, at least in part, and contribute to the development of a global infrastructure for archaeology. This development requires an organic trend of adoption among a widespread community of archaeologists worldwide and is therefore well beyond the control of any individual or research team. However, I have identified three areas in particular that will substantially improve the HSDI going forward, and can be developed at smaller scales within a traditional research program: better incorporation of the archaeological record into the HSDI, sustained interdisciplinary engagement to demonstrate the value of archaeological knowledge to researchers elsewhere in the academy, and careful planning for long-term sustainability.

The improved integration of archaeological knowledge into the HSDI is a logical next step in HSDI-based infrastructure development. At present, the HSDI is still largely composed of data drawn from the historical record. While this record is also a crucial component of any archaeological study of the postindustrial city, archaeologists ultimately need to be able to incorporate uniquely archaeological data into HSDI-based explorations, visualizations and analyses of historical environments. In short, we require something like a "material stage" to complement the HSDI's existing built environment and social environment stages. This will grow from simple beginnings: archaeological

reports, maps, and especially tabular artifact catalogs generated by previous archaeological work in the Copper Country and London, Ontario can be incorporated into CC-HSDI and London HSDI's current structures. Gradually incorporating these into these existing HSDIs can serve as a proof of concept for addressing issues and improving approaches in digital archaeology such as 1) replicating the storage and sharing functions of existing digital archaeology databases such as tDAR and the ADS, but with vastly improved spatialization, visualization, and data exploration options; 2) helping to address the ongoing "data deluge" by better adapting HSDIs for the handling of born-digital archaeology big data (such as remote sensing data) that automatically links each new dataset to all existing data through space and can be further connected through tabular linkages; 3) demonstrate how "orphan collections" of artifacts could be made more visible to researchers. HSDIs may also absorb material culture in other forms. For example, the files generated by 3D scanning of artifacts could be spatialized within the HSDI to either their original archaeological context or current storage repository; these files could then be 3D printed by users of the HSDI. The portability of these printable digital artifacts code blurs the lines between the digital and physical (Reilly, 2015).

The HSDI as articulated within this dissertation is a fundamentally interdisciplinary construct. It could not exist without close collaboration between archaeology and various other disciplines within the social sciences such as history, geography, and heritage studies; it also relies on substantial support from the computer and information sciences. This is not a unidirectional flow, but as yet archaeology has not influenced those disciplines within the context of digital scholarship to the extent that it should. In particular, historical GIS, spatial history, and deep mapping stand to benefit a great deal by greater consideration of archaeological perspectives. The incorporation of archaeological knowledge into HSDI-based historical GIS, spatial history and deep mapping projects will expose geographers, historians, demographers, and others already familiar with these approaches to new, digitized archaeological sources of information on past environments and communities that can counterbalance historically-sourced interpretations – as they regularly do within historical archaeology.

Centering on space as our common point of reference, and working within a common digital platform, can lead to more tightly integrated collaboration and pushes us towards the next steps in pursuing our grand challenge.

Finally, we must consider the overall life cycle of digital infrastructures such as the HSDI, something that clearly remains an underdeveloped aspect of digital archaeology. Developing a web presence for archaeology projects has become commonplace, but equally common is the abandonment or cessation of development of such web projects as funding ends and free or low-cost hosting services are shut down (Law and Morgan, 2014). As innovation in the digital recording, sharing, and use of data within archaeology grows, we face the real possibility of a “Digital Dark Age” in archaeology unless we develop robust, stable infrastructures for the curation of such content (Jeffrey 2012). We are still far from developing a comprehensive, satisfactory solution to this now well-recognized issue (Huggett, Reilley, and Lock 2018).

The indefinite maintenance of large-scale archaeological infrastructures is a key hurdle within the broader grand challenge I have used as the inspiration for my research with HSDIs. For the present, the best attempts to address this issue lie in the support of large-scale digital repositories such as tDAR, the ADS, and ARIADNE (Wright and Richards 2018). With large-scale, multi-institution support, such infrastructures are reasonably well-equipped to maintain their capability in the long-term. However, in the absence of a (more or-less cohesive) globally-supported digital infrastructure for archaeology, we do need to consider alternatives. In an increasingly uncertain funding environment within the social sciences and humanities, how would we deal with funding cuts to levels below what is required to sustain an HSDI such as the CC-HSDI, let alone a more ambitious, larger-scale iteration? How do we build flexibility and resiliency (Huggett, Reilley, and Lock 2018) into digital forms of archaeology?

This is a difficult question to answer, one that likely represents a grand challenge in itself (Huggett, Reilley, and Lock 2018). As a starting point for further discussion on this challenge I suggest that digital infrastructures, like archaeological and historical sites, should always be seen as dynamic rather than static. Our purpose in building and using them should ultimately not be simple preservation of the project or continual

growth of a set program but the management of change. Infrastructural sustainability should ultimately not be seen as linear; an HSDI could have several different “careers” depending on the funding environment and research priorities. From a practical perspective, this means that the design of any digital infrastructure needs to be conceptualized so that the project can continue to exist in a useful, accessible form even if most of the funding required to keep it running at full capability is withdrawn. This could include “plan B” designs for operating the HSDI at a reduced level of functionality in order to keep the project active and publicly accessible in hostile funding environments or between major project initiatives. Such contingency planning should also include developing long-term institutional commitments for basic storage and access functions so that the project can be “paused” without fragmenting. A truly interdisciplinary infrastructure such as the HSDI also benefits from being able to draw on a much wider variety of funding and other resources than one committed solely to archaeology.

This dissertation serves as one answer to the concept of grand challenges for digital archaeology, particularly Costis Dallas’ (2015) call for the development of large-scale digital infrastructures for curating, studying, and sharing archaeological knowledge. Of course, no single “answer” to a grand challenge, however rigorous or innovative it may be, is sufficiently comprehensive in scope to meet that challenge on its own. In demonstrating the HSDI as an approach for the archaeological study of postindustrial places, I have restricted my focus in time space, though I have tried throughout to indicate the potential for a far wider application of the HSDI approach. The success or failure of the HSDI as a contribution to the digital infrastructure grand challenge ultimately hinges on whether it can serve as a useful prototype for “curation-enabled global digital infrastructures” (Dallas, 2015 pg. 176). The scalability of the HSDI concept, based as it is on large-scale curation of big data, makes it well-suited to meet this challenge. While the research team of which I am a member do not have the resources to scale the HSDI up in this way, I have demonstrated in each of study chapters the ways in which an interdisciplinary team can build a substantial, robust, HSDI, and have demonstrated its potential advantages to historical archaeology. The

“global” reach of the concept, however, can only be achieved through the replication of the HSDI by similar teams elsewhere, and by the linking of such HSDIs both to each other and to other existing digital archaeological infrastructures. This dissertation serves as an argument for the value of such endeavors.

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