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A methodology for research in space archaeology: The International Space Station Archaeological Project

Justin St. P. Walsh and Alice C. Gorman

Introduction

Space archaeology is defined as the study of "the material culture relevant to space exploration that is found on Earth and in outer space (*i.e.*, exoatmospheric material) and that is clearly the result of human behavior" (Gorman & O'Leary 2013: 409). The aim of space archaeology is to understand the interaction of technology and human behaviour in off-Earth environments. It fits within the larger field of contemporary archaeology (O'Leary & Darrin 2009; Gorman 2013; Harrison & Breithoff 2017) and adds to the growing literature on the human experience of space (Connors *et al*. 1985; Landfester *et al*. 2011).

This paper presents the methodology of the first archaeological study focused on human habitation in outer space (Gorman 2017; Gorman & Walsh 2017; Walsh 2017). The International Space Station Archaeological Project (ISSAP) aims to extend the purview of archaeology, and provide critical insights about humanity as it moves into the wider solar system. Now at the end of its first funded year, ISSAP is in the process of establishing the data analysis structure to support the methods described this paper. This is the first stage of a much longer project which will offer space agencies and commercial entities evidence-based ideas about how to design space habitats to promote stable societies, and thus mission success.

Space archaeology

Research in space archaeology to date has investigated terrestrial infrastructure such as launch sites, tracking stations, and industrial complexes (e.g. Gorman 2005a, 2016), satellites and orbital debris (Rathje 1999; Barclay & Brooks 2002; Gorman 2005b, 2015; Fewer 2009; Idziak 2014; Walsh 2014), lunar landing sites (Spennemann 2004; O'Leary 2009, 2015; Capelotti 2010; Thomas 2010; Gorman 2016; Westwood *et al*. 2017), and Martian landing sites (Spennemann & Murphy 2009). Much of this literature has been concerned with defining the field and establishing the potential of space material culture to provide new perspectives on the modern world. Further projects have addressed managing the heritage values of terrestrial and lunar space sites (Butowsky 1984; NASA 2011; Walsh 2012; Donaldson 2015; Westwood *et al*. 2017).

While these studies have demonstrated that archaeology can be used to investigate how humans interact with space contexts, so far there have been no substantive analyses of data collected from space sites (Schiffer 2013; Walsh 2015). The principle obstacle to carrying out an archaeological study of a site in space, whether in low Earth orbit or on the surface of another planetary body, is the multi-million-dollar price tag of fieldwork. Only some questions can be answered by remote sensing. For example, NASA's Lunar Reconnaissance Orbiter has imaged the Apollo sites from an orbital distance of 50km, but it cannot see fine-grained detail. Archaeologists who want to study sites of human activity in space must therefore develop other approaches.

The International Space Station Archaeological Project

The International Space Station (ISS) is the only extant, continuously-occupied location in space, with more than 20 years so far. The first ISS modules entered orbit in 1998, and at least two astronauts have inhabited it since 2000 (Kitmacher 2015). It is the largest spacecraft ever built, comprising more than a dozen modules and a habitable volume of approximately 1000m^3, often compared by NASA to a five-bedroom house with a total footprint equal to a football field (Figure 1). With its long history of occupation by groups both large and small (as high as 13 individuals during a fully crewed Space Shuttle visit), and a multi-national, multi-ethnic, and multi-gendered crew, ISS represents the current phase of human adaptations to space.

The station's end-date is currently undecided; and there are moves by NASA to adopt a commercial model of operation (Davis 2018). Eventually, however, all the modules will be de-orbited into Earth's atmosphere, with surviving pieces falling into the 'spacecraft graveyard' in a remote part of the Pacific Ocean (NASA 1996). Thus, ISS will not be preserved in its operational form for future study.

ISSAP is the first project to analyse the social and cultural context of an assemblage relating to the human presence in space. The aim is to investigate how a space culture has emerged and evolved. Archaeology provides a unique perspective which no other discipline can encompass, as demonstrated by other projects on contemporary assemblages (Rathje *et al.* 1992; Schofield 2005; Zimmerman and Welch 2011; Olsen and Witmore 2014; Ralph and Smith 2014;

de León 2015). These investigations have illuminated practices which the subjects themselves either cannot or do not want to articulate. Archaeology can therefore go beyond sociological or anthropological ethnography to interrogate cultural phenomena in space.

Research questions and methods

While there have been discussions of human behaviour in space by sociologists and science, technology, and society (STS) researchers (Battaglia 2012; Vertesi 2014; Messeri 2016; CSA 2017; Valentine 2017; Olson 2018), material culture has not hitherto attracted significant attention. The "small things forgotten" (Deetz 1996) which illuminate human behaviour for the archaeologist are, in fact, usually forgotten.

Questions that can be addressed through the application of archaeological methods include: how people adapt their behaviors and tools to the requirements of life in space; how a crew composed of people from different nations, with different languages and cultures, uses material culture to build cohesion, and manage conflict; gendered use of spaces and objects; identifying spaces and objects associated with work, leisure, rest, intimacy, observation, and surveillance; how the sounds, smells, views, tastes, and textures associated with life on ISS affect crewmembers; how spaces and time are structured to negotiate surveillance and monitoring by ground staff, and interactions with the public; and how microgravity shapes the development of ISS's society and culture.

Without the ability to conduct fieldwork, we have developed a new methodology to allow analysis of sociocultural aspects of life on ISS. These methods are re-imaginings of traditional archaeological practice which take advantage of the ISS's status as an actively-inhabited installation rather than an abandoned site, blurring the traditional boundaries between past and present (Nativ and Lucas 2020). All methods comply with NASA protocols preserving the privacy and anonymity of the crew. The research program includes the following components:

1. Image analysis: using machine learning to catalogue associations between crew members, spaces within the station, and objects/tools.
2. Interviews and anonymised questionnaires with flight and ground crews.
3. Development of procedures for ISS crew to perform archaeological surveys on-site.
4. Investigation of ISS cargo return ("de-integration") activity, and analysis of the values and meanings associated with returned items.

5. Investigation and possibly excavation of archaeological sites on Earth related to the development, deployment, and discard of technology and resources consumed by the crew.

Image analysis

Semiotic analysis of the material culture, coupled with a proxemic analysis of embodied space, provides rich data towards understanding the lived experience in ISS. The first phase of the project leverages the documentation, images, video, and audio media stored by NASA as a proxy for direct observation of ISS culture. Understanding how individuals and groups use material culture in space stations, from discrete objects to contextual relationships, can reveal intersections of identity, nationality, and community.

Fortunately for our research, the occupation of ISS coincided with the emergence of digital photography. The images include metadata recording the time and date, which become the metaphorical stratigraphy of an excavation, linking the images' contents to moments in time. Images depicting the station interior number in the millions, given that the crew takes approximately 400 images per day. As the extensive critical literature on the use of historic photosets as documents for social science research demonstrates, these images should not be taken at face value. The image dataset will be augmented by other NASA data, including the ISS Inventory Management System (IMS), which catalogues every item sent to the space station and its most recent known location (Figure 2). The IMS has over 332 000 records, of which 77 000 are currently active (Adams personal communication 2020). Videos made to survey the surface of the entire station interior every six months for fire-safety purposes will serve as baseline points of comparison for the photo imagery.

Recent advances in machine learning (ML) algorithms have opened new directions in large-scale mining of multimedia data (Resig 2014). This is especially true in image recognition and processing, where deep learning with convolutional neural networks continues to shatter previous limitations in regards to automated classification of imagery data (LeCunn *et al*. 1988; Simonyan *et al*. 2014).

Given the limited number of people who have been to ISS, and the size of the station's interior, machine learning can be used to determine whether there are national, gendered, ethnic, and other identity-associated patterns of occupation of specific spaces (Figure 3). It will be more complicated for ML algorithms to identify objects, necessitating a significant amount of time on the training component of this work to achieve high-quality results. Machine learning and information retrieval has already been applied successfully to build intelligent models of biological, chemical, physical, and medical systems — to name only a few. Space archaeology, however, represents an opportunity to apply these techniques to a domain that so far has yet to benefit from the power of artificial intelligence.

Interviews of flight and ground crews

This method goes back to the original contemporary archaeology investigation, William Rathje's Tucson Garbage Project (Rathje & Cullen 1992), and still further to the basic techniques of anthropological ethnography. Since we are centering the interpretation of photographic evidence, it makes sense to ask the subjects (and authors) of those images about what they think was happening in them. We can also ask other questions about life in space — adaptations that were needed, new abilities discovered, frustrations or limitations encountered, etc. Interviews will supplement questionnaires, as their flexibility allows for responses that do not fit preconceived expectations, or opens up new avenues of questioning as conversations develop. We also hope to engage crew members from various ISS participant space agencies in these interviews, to gain a wider view of life on board. Such interviews, of course, are also interventions in existing communities which may have unforeseen consequences. As part of the space community ourselves, our concern is to maintain trust with interlocutors via informed consent.

Development of procedures for crew to perform archaeological survey *in situ*

Astronauts have conducted an extraordinary range of physical science experiments and research aboard ISS, from genetics, to the physics of fire, to studies of mouse anatomy. Not all astronauts have significant scientific backgrounds, and only rarely does their prior career relate to the research that they perform. Generally speaking, astronauts are expected to be "Jills of all trades" and they receive on-the-job instruction to perform whatever kind of experiment is required.

This method involves writing procedures for one or more crew members to carry out an archaeological survey of the interior of ISS. We are particularly interested in documenting aspects of life on board that cannot be derived from the image analysis, which is a crucial preliminary step before designing the survey strategy.

One survey technique is surface sampling for the build-up of dust, hair, skin cells, oil, dirt, food, broken fragments of equipment, and other materials, analogous to soil sampling through excavation or the Bristol University excavation of their own dig van (Bailey et al. 2009). This method offers opportunities to study the formation of stratified micro-deposits in a microgravity environment, as well as being able to characterise in situ the cultural component of the ‘natural’ microbiome of such a highly curated and structured habitation. The ongoing Aerosol Sampling Experiment, which collects samples of the air and particulates in the space station, provides valuable baseline data for this component of the study. Other techniques include audio recording to identify levels of ambient sound and the extent to which voices and other sounds carry (comparing with previous work such as Aiken 2014 and Goodman & Grosveld 2015); photography to establish lines of sight from various positions, using the full freedom of movement afforded by microgravity; and documentation of specific public spaces such as eating areas, and, if possible, private spaces such as crew berths.

Observation of items returned from ISS

A limited number of items from ISS return to Earth. Since the end of the Shuttle program in 2011, there are only two means for return: a small quantity (50-100 kg) with crew members in the Soyuz craft, and up to 3000 kg on SpaceX’s Dragon capsule. All other materials either remain there, or are placed into other types of supply craft which are destroyed through atmospheric re-entry. Both the Soyuz and Dragon flights happen approximately every four to six months. The returned items are typically scientific samples; broken equipment; and crew personal effects.

The return of items from ISS can be interpreted as a form of discard process. We requested permission from NASA to observe the handling of cargo from ISS on the returns of the Dragon CRS-13 and CRS-14 capsules in January and May 2018, respectively. During our observation, we visited work locations in Houston, TX, and Long Beach, CA; photographed and video-recorded the handling and documentation of the returned items; and interviewed participants in the cargo-return process. Preliminary analysis of the interview transcripts indicates the complexity of the process whereby items enter the inventory and are subsequently dispersed.

Excavation of related archaeological sites on Earth

If items associated with ISS have been discarded on Earth in soil matrices (as opposed to being incinerated or otherwise destroyed), traditional archaeological excavation techniques could be used to retrieve and analyze them. In an interview with a NASA employee for the cargo de-integration study described above, we learned that Kennedy Space Center is a likely site of discard for material returned prior to the end of the Space Shuttle program in 2011. We intend to explore the possibility in future discussions with NASA and other space agencies.

How gravity shapes society

The methods described here are not the only ones which can enable archaeological study of space habitats. Other scholars are likely to conceive of different, even more creative approaches in the future. However, these methods are an important starting point for a subdiscipline which, like its subject matter, is still in its infancy. The six methods in combination will enable deep research into a novel archaeological context. We expect to identify problems and propose solutions that will improve mission success by promoting harmonious social and cultural interactions in future long-duration spaceflight. Such missions are now closer than ever, with several agencies and private corporations planning habitations on the Moon and Mars right now. It is also likely that ISS will soon become a much more commercial enterprise than it has been to date. It is critical to have a baseline of material culture now in order to assess how the change to privatisation impacts on life in space. Finally, the development of this methodology for space archaeology may also be useful for researchers considering contemporary archaeology projects in other remote locations or hostile environments such as under the deep ocean, in polar regions, or in war zones.

Konstantin Tsiolkovsky was an early twentieth century Russian Cosmist with a particular vision of how space travel would affect human culture. He proposed a correlation between gravity, social forms, and the basis of production. In *Outside the Earth* (nd) and other works, he argued that microgravity would create a more equal society. With no seasons, pests, droughts or floods, reliable food crops grow all year round. Solar energy would be freely available to all and could be used to regulate temperature, doing away with the need for clothes. The costs of transportation and construction would diminish to almost nothing as the heaviest materials could be moved or manoeuvred with the merest touch. One of the markers of social status for his time, beds and their accoutrements, would vanish as people could sleep wherever they pleased.

This idyllic version of an egalitarian space society is far removed from contemporary space culture, which is rooted in deep geopolitical divisions between 'spacefaring' and 'non-spacefaring' nations (Gorman 2019), but it does demonstrate the role of gravity in creating or inhibiting access to resources. The consideration of gravity as an agent of social construction underpins our approach to the archaeology of ISS. This extends to theorising the nature of the human body and its affordances in different gravity environments. In microgravity, vision, smell and taste are significantly altered, usually in ways considered to be problematic. Other qualities are enhanced, such as speed and strength. While microgravity provides major challenges for Earth-adapted physiology, it also creates opportunities. Eveleth (2019) has pointed out that conditions considered disabilities on Earth are not constraints in the same way in space. For example, loss of inner ear function, leading to deafness, can also make the person immune to space sickness. At present, the population of astronauts is dominated by a particular kind of elite body, which tends to be white, male, and military, reinforcing the socially dominant human body of terrestrial gravity. This phenomenon may or may not change in the future, but contextualizing the space body as a variant rather than aberration also de-centres terrestrial gravity and opens new avenues for understanding Earthly phenomenology. The extent to which the material technologies of everyday life are structured by 1G gravity will only be evident in contrast with the situation where they are not. Archaeological analysis of the ISS is an opportunity to make a familiar feature of terrestrial life unfamiliar (Buchli and Lucas 2001), inviting comparison with how diverse communities past and present on Earth use material culture to respond to the constraints and potentials of a particular gravity regime.

Both space and time have to re-evaluated outside Earth. ISS travels at a speed of approximately 7km/s, completing an orbit in about 90 minutes. Once every 45 minutes, the crew witness a sunrise or sunset. Day and night, light and dark, do not play the same role in structuring human behaviour as they do on Earth. Against this background, the photographs which are the focus of our study are more minute divisions of time, capturing a stillness in perpetual motion. As time slices, each is a digital Pompeii which requires just as much interpretation. Understanding how these moments come to build a structure, a tradition and a society in space is the ultimate goal of ISSAP.

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Figure 1: The International Space Station in 2010. Image courtesy of NASA

Figure 2: Astronaut Chris Cassidy unloading food supplies in June 2020. Note the directional labelling (port, aft, forward) around the hatch, which ISSAP is using to describe object and crew location within images. Image courtesy of NASA.

Figure 3: Astronaut Koichi Wakata in the Zvezda module in 2014. The Soviet modules are characterised by the use of green shades in the interior. Image courtesy of NASA.