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研究課題名（和文）Estimation of Jomon period pithouse energy costs through the use of reconstructions

研究課題名（英文）Estimation of Jomon period pithouse energy costs through the use of reconstructions

研究代表者

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研究成果の概要（和文）：この研究中に、写真測量を使用して復元竪穴住居の再現を記録する信頼性の高い方法を開発した。初期の生スキャンはサイズが大きすぎて取り扱いにくかったが、3Dモデルからの高解像度データを利用する方法を開発した。初期のテストケースに基づいて材料コストを計算し、残りの3Dモデルに対しても同様の計算を早急に行う。このプロジェクトで12の復元竪穴住居をスキャンし、異なる形式の竪穴住居の初期セットを作成した。この研究で収集されたデータと克服した技術的な課題は、異なる竪穴住居タイプ間の材料とエネルギーのコスト差をさらに調査するための必要な基盤を提供した。

研究成果の学術的意義や社会的意義
このプロジェクトは、異なる縄文時代の竪穴住居タイプの材料コスト差を定量化し、それらの変化が何に関連していたかを調査する最初のステップである。このプロジェクトで開発された3Dスキャニングとモデル測定の技術は、他の類似プロジェクトにも適用可能であり、このプロジェクトで作成されたスキャンは測定に役立つだけでなく、将来のデジタル教育プログラムでこれらの構造を仮想的に体験するためにも使用できる。このプロジェクトに関する発表を通じて、日本国内外で縄文文化についての情報をより多く共有することが可能になった。

研究成果の概要（英文）：The goal of this research is to better understand Jomon residential mobility through the examination of different pithouse types. Prior research has shown a correlation between the amount of materials and energy put into a dwelling its intended use life. Dwelling size affects these costs, but so can building configurations. I made 3D scans of pithouse reconstructions, which were used to create material and energy cost estimates. I developed a reliable method for scanning pithouse reconstructions using photogrammetry. Initial scans were too large to work with, but I created a way to get accurate measures from the high resolution scans. I calculated material costs on a test model and will do the same to the remaining 3D models. I scanned twelve pithouses, created an initial set of pithouse types. The data gathered and the technical challenges overcome in this project created a foundation to continue examining material and energy cost differences between the different pithouse types.

研究分野：archaeology

キーワード：archaeology　mobility　3D　photogrammetry

様　式　Ｃ－１９、Ｆ－１９－１（共通）

１．研究開始当初の背景 Background at the beginning of the research

This project began as an attempt to gain insights into Jomon residential mobility through the examination of pithouse features. Ethnological research has shown a correlation between the amount of applied material and energetic resources to a dwelling and the intended duration of occupation and/or the number of times that dwelling is intended to be occupied. A hastily constructed dwelling of expedient resources is a low-cost endeavor but due to its lack of durability, it will need to be repaired or rebuilt quite often if used for a long duration of time. On the other hand, a solid structure using more intentional and standardized materials will require less maintenance over time but will require a greater up-front cost. While there are plentiful records of pithouses, the archaeological remains of the pithouses themselves are quite limited. We can observe the main pit that was dug for the dwelling as well as the postholes for the supporting posts and pillars for the structure, but we don’t know much regarding what was present above ground level. The general size of pithouses can provide some insights into related energy and material costs, but the varying arrangement of pithouse types are also likely to be a significant factor in these costs and have yet to be compared in a quantifiable manner. This is where information gathered from pithouse reconstructions might prove insightful.

Japan has a long history of pithouse reconstructions, and while there are a variety of different interpretations of how Jomon pithouses may have been constructed, they can all be considered as a form of experimental archaeology. Additionally, as many of these structures have existed and been maintained for extended periods of time, we can be sure that the general construction principles behind these interpretations are reasonably sound from an architectural standpoint. By gathering material and energy cost estimates from a variety of different reconstructions, we could start to derive a range of estimates for the different pithouse types. While this wouldn’t provide a definitive answer for cost differences between different pithouse types and sizes, it could provide some initial comparisons as well as a foundation for further investigations.

２．研究の目的 Purpose of research

The purpose of this study was to quantify differences in energy costs involved in the construction of different types of Jomon pithouses. A better understanding of the material and energy costs associated with different pithouse types would help provide a better understanding of possible reasoning behind the changes in those types, including changes of residential mobility.

While some energy cost estimates for individual pithouses have been conducted, we lacked more comprehensive comparative studies investigating energy and material costs related to different Jomon pithouse types. Current approaches to prehistoric population estimates often involve examining the number of dwelling remains that archaeologists have found and how those counts change over time. The simple assumption is that more pithouses would equate to an increasing population, while a decreasing number of dwellings would indicate a decreasing population. While on its face this seems a reasonable assumption, it doesn’t take into account how long or how often these dwellings are used. A sturdily built dwelling may only need to be rebuilt once or twice during a generation, while more expedient structures may need to be rebuilt after only a year or two. All pithouse structures are not equal, and in addition to the size of these structures, the configurations in which they were built likely also played a significant role in their intended use lives, but the research into these differences was lacking. The project aimed to start a deeper investigation into these differences, serving as a foundation for further comparison studies and leading to a better understanding of architectural changes and possibly related residential mobility changes during the Jomon period.

３．研究の方法 Research method

Although in their totality Jomon pithouses are fairly simple compared to modern dwellings, the framing structures of the different pithouse reconstructions can be fairly complex. A single small reconstructed pithouse consists of hundreds of individual components, many of which are fairly inaccessible and difficult to measure. Individual pithouse components would be difficult and time consuming to gather manually due to these issues and the recording process itself would be quite complex as a general plan of the entire structure and subcomponents would need to be mapped out beforehand in order to keep measurements organized. As these structures are typically open to the public, it was important to try to minimize the impact that this recording process would have to the caretaking organizations as well as their visitors. Taking these factors into consideration, it seemed that if a scaled recording of these structures could be taken on-site, the actually measuring process could be done off-site, minimizing the impact to these locations.

Structure from motion (sfm) photogrammetry was chosen as the best way to record these pithouse dimensions due to the general affordability and flexibility of the approach. This process uses specialized software to analyze data from a series of overlapping photographs to identify the camera's location in space, which is then used to create a 3D model of the subject. Using photogrammetry to create 3D models of pithouse reconstructions provided a number of benefits. It allowed for a more efficient means of recording the structures compared to recording by hand; the simplified versions of the models can be used to explore how modifying aspects of the structures, such as changing their height, will affect total energy costs; and the in the course of collecting this information a digital "copy" of the structure is created and can be preserved for far longer than the usual lifespan of these structures.

The pithouses provided some difficult challenges in terms of 3D capture. The poorly lit interiors required additional powerful lighting to illuminate occluded areas within the structure. The height of the structures required the camera to be attached to a tall camera pole and triggered either remotely or automatically in order to get a clear view of the exterior roof structure. The interior pillars were difficult to record clearly within the context of the pithouse interiors due to camera depth of field limitations, and some parts of the pithouse interiors were impossible to capture clearly due to limited interior space to record the areas from multiple angles. The processing of the models themselves was the next challenge. Pithouse scans included upwards of over 1000 images and the resulting models could end up consisting of billions of polygons. Simplifying the models to sizes that were able to be manipulated in other programs was a significant challenge. In the end the combination of recording high resolution slices combined with a lower resolution general mesh was the best approach to ensure measurements that were as accurate as possible while still allowing reasonable flexibility to record areas where capture resolution was poor.

Once the pithouses were captured, processed, and exported in more easily, the next step was to calculate the amount of materials used in the construction of the pithouse reconstructions. From here the energy required to process these materials and to construct the pithouses could be calculated using information gathered from prior ethnographic studies from both inside and outside of Japan. While environmental conditions, tool types, and processing techniques vary, tasks such as digging holes, cutting trees, and making cordage are fairly straightforward, and a range of relatively accurate time cost values can be determined using these prior studies.

Once these calculations are completed across the different pithouse types, the material and energy cost amounts can be compared to determine if there are any significant variations amongst the different types in regards to material and energy costs. Using the basic foundational construction techniques from the different approaches to pithouse construction, results can be scaled in terms of floor space as well as roof height to explore alternative material and energy costs of the different pithouse configurations.

４．研究成果 Research Results

During the first fiscal year of the project I purchased the initial camera equipment and built a scanning rig that allowed for the camera a large strobe unit to be mobile enough to use within the confines of a pithouse. In order to help reduce the specular reflection from smooth support structures within the pithouses I created a custom polarizing filter mount for the ring flash. The initial test case was an educationally focused pithouse reconstruction at the Kyoto Prefectural Yamashiro Regional Museum. Due to subsequent travel restrictions related to Covid-19 this was the only pithouse reconstruction recorded for the year. The initial model still provided a good foundation to explore different processing approaches for the 3D model including the selective export of main pillar structures for individual measurement, the isolation of framing structures through the digital removal of thatching from the structure, and a variety of mesh decimation approaches to try to retain as much detail as possible while reducing the overall model size to a manageable file size.

In 2022 due to some continuing complications due to Covid-19 I was unable to travel to as many pithouse sites as I had intended. Despite the complications I was fortunately able to record three additional pithouses in Yamanashi prefecture at the Umenoki site. The data set for the three resulting models utilized over 2500 images. Several changes were made for this new capture process. Additional scale bars using machine-readable AprilTags were used to ensure proper scaling of the pithouse with multiple scale bars placed within the thresholds of the pithouses to help combine the interior and exterior portions of the scans. A camera pole capable of extending over seven meters was used to ensure clear coverage of the tops of the pithouse reconstructions. Light falloff due to the wide lens used for capture combines with a somewhat focused flash pattern from the ring light used in the initial pithouse scan in Kyoto resulted in significant vignetting of the recorded images. To combat this issue a wide reflector dish was used to provide a more even light pattern for the pithouse scans. This resulted in more evenly lit images but removing the polarized filter on the light resulted in more specular reflections on inner support structures, which in turn resulted in misalignments during the meshing process. Additional work was still done in terms of simplifying models, but a significant amount of effort was still required in the model processing and results were not as precise as initially intended.

In 2023 I traveled to scan pithouse reconstructions at four additional locations: the Umataka Jomon Museum (Nagaoka City, Niigata prefecture), the Najomon Jomon Period Museum (Tsunan Town, Niigata prefecture), the Jomon Village (Tama, Tokyo), and the Kasori Shellmound Museum (Chiba City, Chiba prefecture). I was also able to make an additional trip to Hokuto city in Yamanashi prefecture to scan an additional pithouse at the Umenoki site. In all I was able to scan an additional eight pithouses, bringing the total up to twelve if including the initial test case in Kyoto and a total image count of over 12,000. Despite it being fewer pithouses than initially intended, a wide variety of pithouse types were still able to be captured. The data set includes pithouses with rooves made out of both thatch as well as bark, soil and sod; pithouses with as few as three and as many as either main interior support pillars; a rectangular "longhouse" type pithouse from the Umataka site as well as a stone-lined pithouse from the Tama New Town site.

After several years of trial and error, I eventually derived a processing methodology that allowed me to utilize precise measurements from the 3D scans where possible and still provide reasonable measurements in areas with poorer coverage. In RealityCapture, the main photogrammetry processing software for this project, I created a number of cross sections which were exported as Drawing Exchange Format (DXF) files. These were imported into Blender and could be converted into a mesh format withing Blender to allow for easier point to point measurements. A lower poly OBJ file was also exported which served both as a background to help better understand the exported cross sections, but also as a reference source in the event that a clear measurement couldn't be taken using the cross sections. Using the Umataka pithouse as an initial test case I made a total of over 700 measurements of the 167 individual framing and support members in the structure. Multiple diameter measures were taken in order to obtain an average diameter value that could be used in subsequent calculations.

Although work is still ongoing on the project, within the span of this Kakenhi research start up grant I have developed a reliable method for recording pithouse reconstructions using photogrammetry. While models with large file sizes and poly counts over one billion were initially a significant difficulty in utilizing the scans for digital measurements, I was able to develop an approach that both took advantage of the high poly nature of the models while still providing an alternative means of measurement when that data was lacking. Initial measurements have been calculated on an initial pithouse test case and a similar approach will be applied to the remaining 3D models. This project provided an initial data set to cover a variety of different pithouse types which will continue to be processed and compared in continuing research to identify any significant material or energy cost differences between the different pithouse types. Initial results of this project have been shared at international conferences as well as in several local educational workshops and will continue to be shared as research progresses.

5．主な発表論文等

〔雑誌論文〕　計0件

〔学会発表〕　計1件（うち招待講演　0件／うち国際学会　1件）

１．発表者名 NOXON, Corey Tyler
２．発表標題 Estimating Energy Costs with Pithouse Reconstructions and Photogrammetry
３．学会等名 Computer Applications and Quantitative Methods in Archaeology (CAA)（国際学会）
４．発表年 2022年

〔図書〕　計0件

〔産業財産権〕

〔その他〕

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6．研究組織

	氏名 （ローマ字氏名） （研究者番号）	所属研究機関・部局・職 （機関番号）	備考

7．科研費を使用して開催した国際研究集会

〔国際研究集会〕　計0件

8．本研究に関連して実施した国際共同研究の実施状況

共同研究相手国	相手方研究機関