Rediscovering Provo's First Tabernacle with Ground-Penetrating Radar

John H. McBride, Benjamin C. Pykles,
Emily Utt, and R. William Keach II

During the early morning hours of December 17, 2010, fire broke out in the Provo (Utah) Tabernacle, virtually gutting the historic building and leaving only the exterior walls standing in stable condition. On October 1, 2011, The Church of Jesus Christ of Latter-day Saints announced that the ruined tabernacle will be restored as the second temple of the Church in Provo (the Provo City Center Temple), giving a second life to the tabernacle. However, this building is not the first tabernacle in Provo. Many years before the present tabernacle was constructed, the "Old Tabernacle" (or "Old Meeting House") stood immediately north of the tabernacle that burned (figures 1 and 2) (in this article, we will refer to the Old Tabernacle as the first tabernacle and the burned Provo Tabernacle as the second tabernacle).

The first tabernacle was razed in 1919. Over time, this building and all associated structures disappeared from the surface of the site, replaced by open landscaping north of the second tabernacle, and the exact location of the old building was forgotten. Prior to the excavation of the first tabernacle site, the roots of a great sycamore tree had spread beneath an area once occupied by the north entrance of the first tabernacle. Underneath the tree's towering branches, generations of picnickers have unfolded their blankets on the ground, little aware of the rich legacy buried there.

Because the area of the first tabernacle will undergo extensive modification in preparation for the new Provo City Center Temple, it was critical to understand the location and character of the buried nineteenth-century structures in order to provide information that could be used to help plan the development. As part of the preparation for the construction of the new temple, a three-dimensional (3D) ground-penetrating radar (GPR) study of

Figure 1. Photograph of the first tabernacle in Provo, Utah, located near what is now the intersection of University Avenue and Center Street, looking southwest. Photo © Utah State Historical Society.

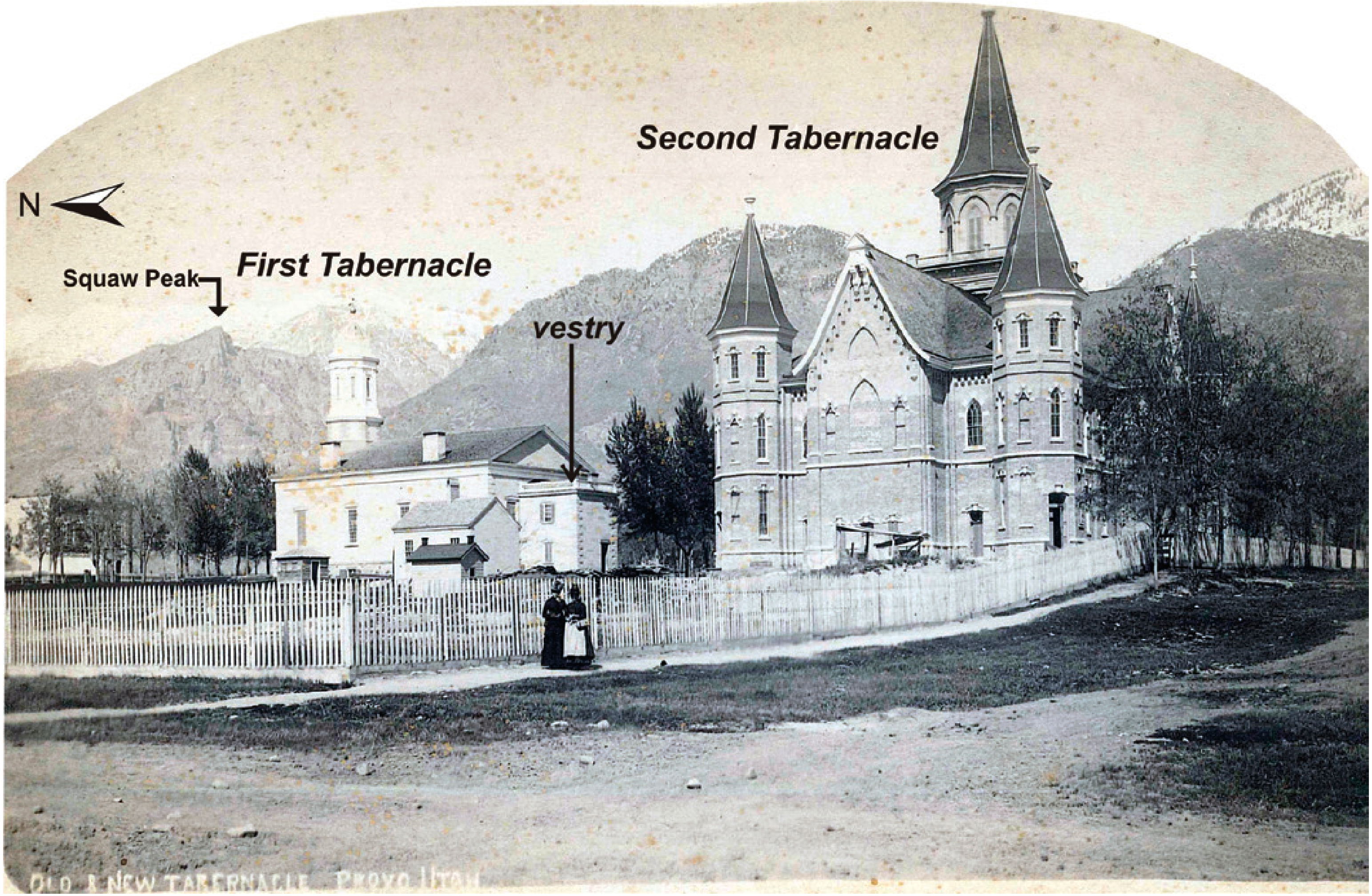

Figure 2. Photograph taken from near the intersection of present-day 100 South and 100 West in Provo, looking northeast. Photograph courtesy of the Church History Library.

the area north of the second tabernacle was undertaken in November 2011 to assess buried archaeological resources associated with the first tabernacle. Modern understanding of the first tabernacle has been based primarily on written and photographic sources. These sources, although excitingly rich, do not provide all of the necessary details about the building to plan a major development of the site. In this article, we report the results of this investigation to demonstrate the value of GPR for interpreting the foundations and interior structures of an important pioneer building.

As part of our study, we investigate how radar can noninvasively produce high-quality, interpretable images of buried nineteenth-century structures typical of historic sites in urbanized areas. The degree to which GPR can sharpen our knowledge about the location, dimensions, and physical interior of a nineteenth-century building site is also studied. Lastly, we show how the results reveal the location and nature of buried features, such as foundations, interior walls, interior and exterior entrances, and variations in the preservation of buried remains that could impact subsequent development of the site. To put it simply, we wished to see if any substantial foundation stone remained at the site. Such a question was brought home to us as we were working at the site when a passerby "warned" us that we would find nothing because the townspeople would have carted away all the stone to be used elsewhere.

Our interpretations of the GPR results were tested initially by excavating strategically placed pits in order to verify the existence and precise location of the buried foundation, followed by a full-scale excavation of the site by professional archaeologists from the Office of Public Archaeology at Brigham Young University. To the best of our knowledge, this study represents the first published 3D GPR study of a historic LDS Church building. In general, our study provides a good case study of how the 3D GPR technique can be used to assess buried historic architectural remains that are not expressed at the ground surface and for which physical documentation is incomplete or unavailable. Further, the subsequent archaeological excavations provided a rare opportunity to assess the effectiveness of GPR for detecting fine-scale features of the buried building.

Brief History of the Survey Site

Construction of the first tabernacle began in 1856 under the direction of Brigham Young. The building's design likely came from Church architect Truman O. Angell. The building was apparently designed to preserve "among us a reminiscence of a Presbyterian meeting house, that the children of the Saints might see in what kind of an edifice many of their fathers worshipped before they heard the Gospel."[1] Construction proceeded slowly with brief bursts of activity. The building was dedicated in 1867 by

John Taylor, a member of the Quorum of the Twelve Apostles. The hall was filled to overflowing with Church leaders and Provo residents.

The building was approximately 81 ft. by 47 ft. (24.7 m by 14.3 m) with a rough stone foundation and adobe walls. The exterior walls were stuccoed and incised to create the appearance of stone. The wood roof was capped on the north end with a large bell tower. The main entrance was on the north gable end of the building. Entrances on the east and west provided access to a full basement the same size as the upper hall (figure 1). A two-story vestry about 18 ft. by 18 ft. (5.5 m by 5.5 m) was constructed on the south gable end of the building (figure 2). This vestry probably did not have a basement. The tabernacle's main room included a balcony on the east, north, and west and had a large pulpit on the south wall. Structural support for these interior elements likely came from columns extending through the basement and main upper hall. There was some kind of vestibule inside the north entrance, but documentary sources are not clear about its overall dimensions. Interior finishes were made of plaster or painted wood.

At the time of dedication, the tabernacle was already deemed too small for the increasing Provo population. In 1882, construction began on the second tabernacle. The two tabernacles shared the same city block, with the new building facing east. The first tabernacle was subsequently used less frequently and eventually fell into disrepair. When the first tabernacle was demolished, adobes were removed for use in other buildings and the foundation was removed to a few feet below grade. With the demolition, precise information about the building's location, size, relationship to the new tabernacle, and exact footprint was lost.

Historical sources also reveal information about other structures on the tabernacle block. In the area west of the two tabernacles was a caretaker's brick cottage, a wood support structure of some kind, and an enclosed baptismal font. These structures appear in photographs (see figure 2), but little is known about construction dates, dimensions, or demolition.

Primer on GPR Surveying

GPR is a kind of radar, similar to that used at airports to safely guide airplanes to the ground, except GPR sends signals into the ground instead of through the air. GPR profiling uses an electromagnetic signal that is transmitted and received by the antenna unit. Radar images are derived from the "echoes" of the signal that reflect back from surfaces or objects buried in the ground and are recorded by a computer attached to the antenna. Stone or brick foundations, rubble from the demolition process, and interior walls are examples of buried building material that could produce such echoes. Buried surfaces or objects that strongly reflect (or scatter) radar energy back to the antenna do so because their electrical properties contrast with the surrounding soil, meaning that they have different "reflectivity." For example, a buried foundation stone that is composed mostly of quartz (a form of crystalline SiO_2) has a reflectivity that varies markedly from that of soil. This is partly because the stone possesses a lower porosity relative to soil (soil has more air space—more porosity—than the stone). Since the speed of electromagnetic signals in air is much greater than that in quartz,[2] radar energy is reflected back from the stone to the antenna. Moisture content of the site is also important; as moisture increases, electromagnetic signals slow down and become attenuated. GPR data are recorded as energy arriving at the antenna over time (a typical range of recording time is 100 nanoseconds [ns]), and so the images must be converted to depth using an assumed or derived signal velocity for the soil overlying the target.[3]

During a site survey, the GPR antenna and recording computer unit is moved by hand across the ground along a series of closely spaced parallel and perpendicular lines in order to produce a grid of data. In this case, lines were spaced 1 ft. (0.3 m) apart. The GPR data grid is processed using specialized software and can be viewed as maps at various depths below ground surface ("depth slices") or as cross sections ("profiles"). The advantage of the 3D approach for imaging a buried building with GPR lies in the researcher's ability to view the subsurface as a "volume" of data that can be sliced or cut at various depths in order to view individual rooms or stone walls, or to determine where entrances or walkways might have been.

One of the early uses of GPR was to locate buried foundations or other structures associated with archaeological remains.[4] Brigham Young University researchers have previously applied GPR and other radar technology to the fields of archaeology, climate-change science, weather science, and geology.[5] Archaeological applications of GPR to historic sites in Nauvoo, Illinois, sponsored in part by Brigham Young University, are currently ongoing.[6]

Design of GPR Survey over the First Tabernacle Site

Prior to conducting the GPR surveys, we began our sleuthing of the first tabernacle site by consulting late nineteenth- and early twentieth-century Sanborn Fire Insurance maps for the state of Utah, which show an "adobe/fire-proof" building labeled "(Old) Tabernacle" situated north of the present Provo Tabernacle.[7] The Sanborn maps are an indispensable resource used by historical archaeologists investigating urban areas because they not only show precisely where many old buildings were located but also track structural changes to these buildings that might affect their insured value.

For example, the Sanborn maps show a number of changes to the first tabernacle site, such as the removal of the front porch on its northern entrance sometime after 1888.

The likely location of the first tabernacle with respect to the northern wall of the second tabernacle was estimated from the Sanborn maps, and, from this information, an initial GPR grid was laid out (grid 1, figure 3). This initial grid was intended to locate most of the old building, but in fact it covered only its northeast quadrant as revealed by the first surveying efforts. Once we discovered this quadrant, we then were able to add two additional grids, which had to be positioned so as to avoid the large sycamore tree and the security fence that restricted access to the second tabernacle site. The ground surfaces for grids 1 and 2 (the landscaped area) and for 3 (the restricted area) were quite different, which impacted the quality of the GPR results. The smooth grassy surface of the landscaped area provided an excellent platform for data collection, whereas the restricted site was covered with an approximately 6-in. (15.2-cm) layer of coarse slag (used to stabilize the muddy site) that caused the antenna to bounce slightly as it was moved across the ground and impeded radar reflection, thus degrading the signal somewhat. With the survey areas precisely laid out, we began the tedious task of pushing the antenna back and forth across the ground, rather like meticulously mowing a large lawn. Fortunately, a small army of students volunteered to help.

Results and Interpretation

Once all three grids were surveyed by the GPR over several days, the data were loaded into a computer using specialized software, and three 3D "volumes" were created that could be cut up into vertical or horizontal slices. The horizontal slices, or maps, can be presented at various levels below the ground surface. For example, at a depth of 2 ft. (0.6 m), one can see linear anomalies (straight lines that clearly stand out, see figure 4) as well as oddly shaped dendritic patterns (sinuous, branching lines, see figure 4). The former are simply shallow buried utility lines, whereas the latter are roots emanating from the large sycamore tree that once commanded the site. The precise delineation of buried pipes and tree roots demonstrates the level of detail possible with GPR surveying with a fine 1-ft. (0.3-m) grid.

When the GPR maps are visualized at an optimal averaged depth of 2 ft. (0.6 m) below ground surface (figures 3 and 4), distinct rectilinear outlines of a building start to emerge. In grids 1 and 2, it is easy to see interior partitions within the northern part of the structure, related to a foyer or entrance hall. Also visible are remnants of a rectangular front porch structure (shown

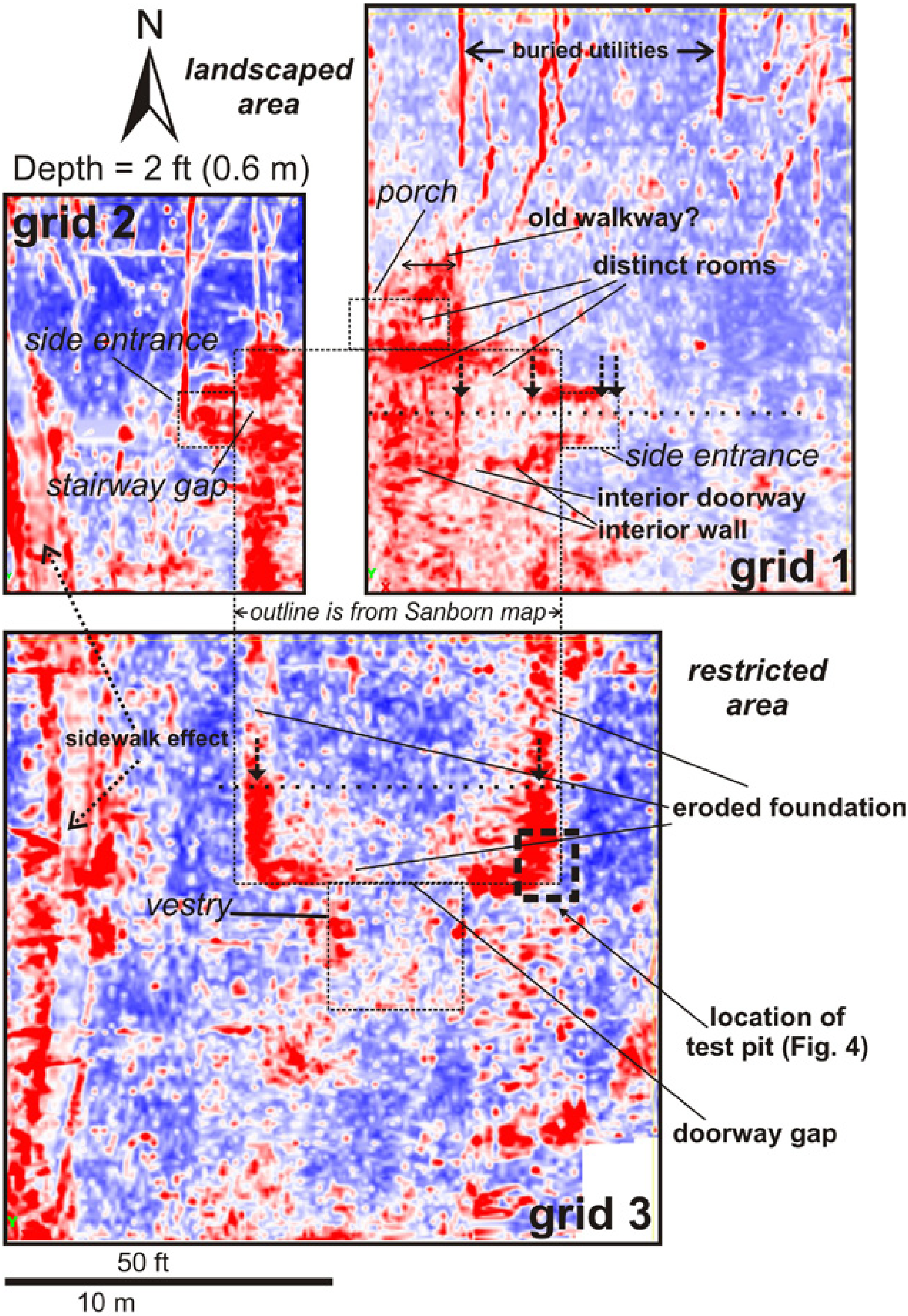

FIGURE 3. Depth "slice" (map) cut through the GPR volume at 2 ft. (0.6 m), averaged over an interval of 2 ft. (0.6 m), assuming a speed of light through the ground of about 0.3 ft./ns (0.09 m/ns). Locations of interpreted features are noted. Also shown is the outline of the first tabernacle as taken from the 1888 Sanborn Fire Insurance map. Horizontal dotted lines show the position of the profiles in figure 6, and vertical black arrows indicate divisions observed on the profiles.

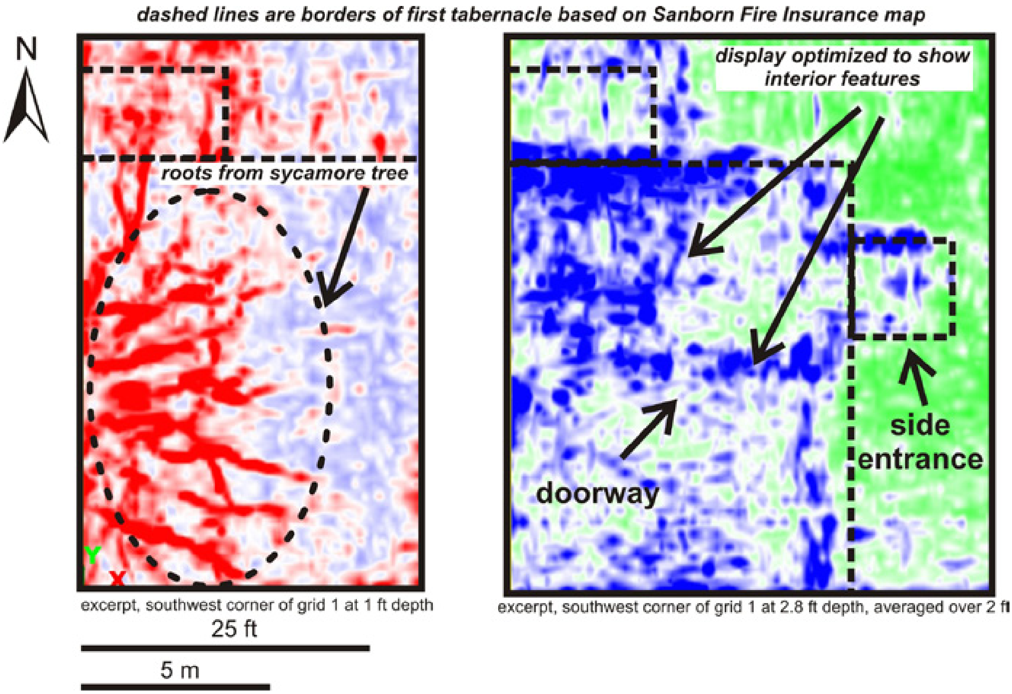

FIGURE 4. Map excepts from grid 1 showing details (left) of shallow tree root patterns associated with a large sycamore tree and (right) of interior partitions.

as a frame structure on the 1888 Sanborn map) on the north side of the building, as well as small square stone basement entrances on the east and west sides of the building. Both of these features are evident on historical photographs (figures 1 and 2). The high reflectivity of the boundaries of the basement entrances, relative to the lower reflectivity of the porch, confirms that the former were composed of thick stone foundations, which remain intact. The porch likely had thinner foundations, which accords well with this being a frame substructure. Two parallel curved lines can be seen leading away from the north entrance that may be remnants of a walkway into the building (figure 3).

Differences in reflectivity between different partitions (see figure 4) point to varying types of materials that either originally existed within the partitions or that were dumped into the structure as part of the demolition process. Observing these changes in reflectivity is useful for guiding further archaeological study of the site or for planning further development. The origin of the internal reflectivity is likely to be collapsed and discarded building stone, rubble, or other material thrown into the interior as fill.

In addition to showing variations in the internal partitioning of the building, the GPR maps provide estimates of the thickness of the walls. For example, the north-south walls appear to be about 4 ft. (1.2 m) thick, which is confirmed by the test pit (figure 5) excavated by staff and volunteers of the Office of Public Archaeology at BYU. The data quality of the grid 3 survey appeared to suffer due to the slag layer and so does not show internal reflectivity as well, although the main foundation walls are well expressed. Interestingly, the grid 3 area demonstrates strong variations in the expression of the foundation walls. For example, there is a gap in the rear wall adjacent to the vestry, which is fixed to the southern end of the building (figure 3). Looking at the east and west walls in grid 3, one can also see gaps expressed as a weaker signal. Although the southern vestry area manifests some GPR signature, it clearly does not have the same strong structural outline as the rest of the building's footprint, which suggests that it may not have been built on as solid a foundation as the rest of the structure. This observation is consistent with the historical record, which indicates that the vestry probably did not have a basement, a fact that was confirmed by the BYU excavating team. The overall geometry of the GPR-derived structure agrees generally with the relative dimensions from the Sanborn maps.

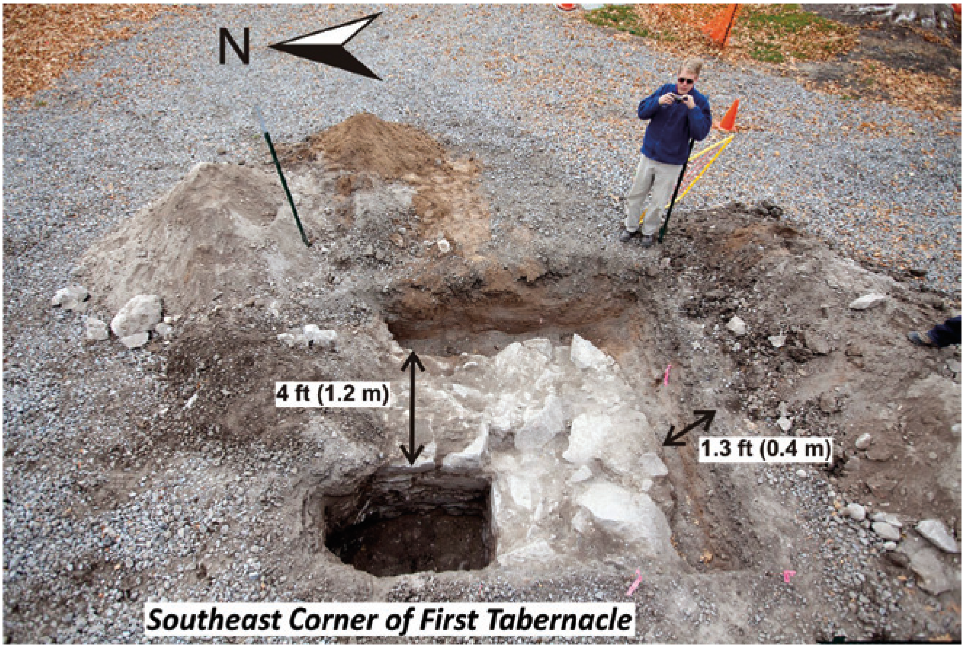

Figure 5. Test pit over the southeast corner of the first tabernacle foundation in grid 3 (see figure 3). Small rocks covering the ground are slag brought in to stabilize the muddy site. Person in photo is author Benjamin C. Pykles. Photo by Jaren Wilkey/Brigham Young University.

As we lower the investigation to deeper levels, the reflectivity dies out at 6–7 ft. (1.8–2.1 m) below the ground surface, the depth one might expect for the base of the interior structure. This can be visualized by slicing the 3D volume vertically in order to provide the interpreter with cross-sectional (or profile) views through the buried building. For example, a profile cutting across the grid 3 area shows the discrete locations of the buried walls and provides an estimate of their depth and thickness (figure 6). Also visible in profile view (figure 6) is the base of the interior structure in grid 3, as estimated by the cessation of reflectivity caused by stone rubble or other debris that was laid on top of natural geological deposits. Profiles over portions of grid 1 show the lateral variability of internal reflectivity of partitions or rooms within the northern part of the first tabernacle. This reflectivity variation indicates that these partitions were filled with a varying degree of stones, bricks, or other material during the demolition process. Test pits confirmed that the base of the foundation wall was indeed 4–5.5 ft. (1.2–1.7 m) deep below the tops of the existing foundation (or 6–7 ft. [1.8–2.1 m] below grade) and that the structure's basement floor consisted of undisturbed sand deposits underlying a thin layer of clay (in other words, a prepared surface) on which sat large amounts of stone rubble resulting from the demolition process.

Validation of GPR Results from Archaeological Excavation

Shortly after the GPR survey, archaeological excavation by BYU's Office of Public Archaeology commenced, under the supervision of Richard K. Talbot, director. The full-scale excavation of the first tabernacle site provides a unique opportunity to test the validity of the interpretation of the GPR results. Such an opportunity is particularly valuable since the usual purpose of a GPR survey is to avoid the necessity of a complete excavation. The exposure of the site thus allows us to benefit from hindsight and understand how particular characteristics of the buried remains are expressed in a radar image. Once the excavation was completed, the LDS Church History and Special Projects departments teamed up to engage a contractor to generate 3D laser scans of the exposed site using terrestrial-based LiDAR (Light Detection And Ranging) and digital photogrammetry, from which one can synthesize 3D views from any vantage point with up to 1-mm accuracy (figure 7). Images created in this way can also aid in validating and guiding the interpretation of the radar results.

One of the more obvious features of the radar map image (figure 3), other than the outer foundation walls, is an inner partition that cuts through the northern half of the structure. The excavations exposed this feature as an inner, east-west-trending wall along with the remnants of two equally spaced doorways, one of which is expressed as a subtle gap in reflectivity in the GPR

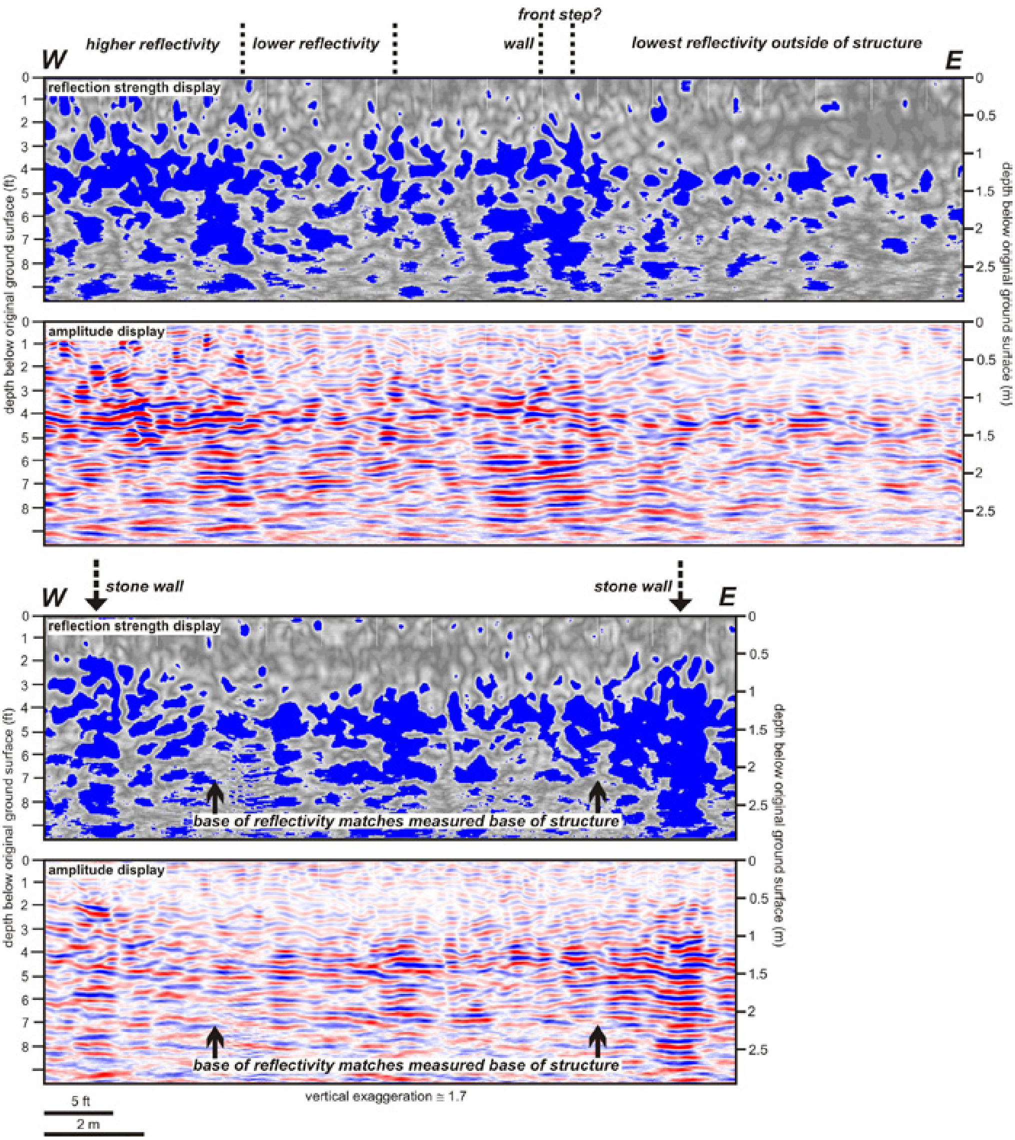

FIGURE 6. Cross sections through grid 1 *(top),* showing variation in reflectivity between two partitions, as well as individual foundation walls, and grid 3 *(bottom),* showing distinct foundation walls and the base of reflective zone, corresponding to a layer of rubble as verified in test pits. See vertical dashed lines in figure 3 for the location of the profiles.[8]

Figure 7. Aerial LiDAR view of the fully excavated site.

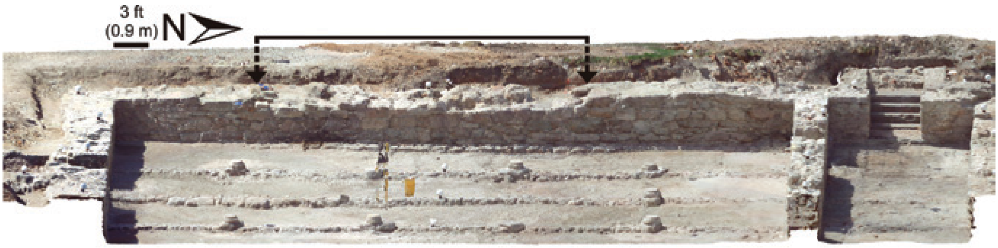

Figure 8. Oblique LiDAR view, looking west, showing the west wall of the first tabernacle. Vertical arrows indicate area of the west wall that is eroded. Note the variation in roughness and erosion of the wall, which is manifested as a weakened radar signal in figure 3 (western area of grid 3).

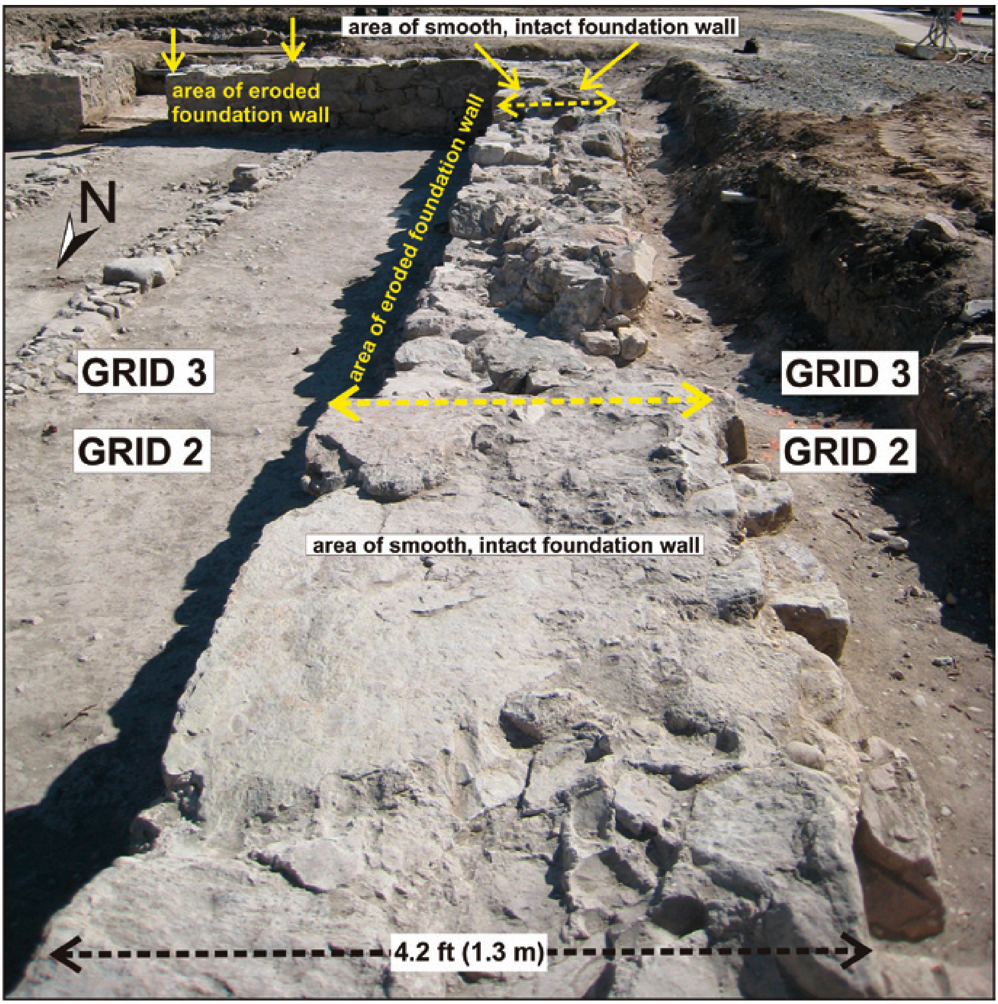

Figure 9. Oblique ground-based photograph (by J. H. McBride) taken along the western foundation wall looking south, showing variation in roughness of the wall.

data from the grid 1 survey (figure 4). Rectangular-shaped variations in reflectivity in this area (figure 4) turn out to be related to variations in the degree of rubble that had collapsed or been pushed into the interior of the structure. Over the southern part of the structure (beneath the "restricted area" in grid 3, figure 3), stark losses in the reflectivity of the main foundation walls were initially thought to be caused by an unexplained noise problem; however, the excavations revealed drops in reflectivity to be directly related to the increased roughness and erosion of the buried upper surface of the foundation walls in these areas (figures 8 and 9). The gap in the southern wall of the main foundation turned out to be a doorway into what was the vestry, which was attached to the southern wall. The poor expression of the vestry area (south of the main structure), a consequence of the much thinner foundations beneath it, can be seen in the view of the fully excavated site (figure 7).

Summary and Conclusions

Our study is "hypothesis-driven" in the sense that we knew more or less where to locate the geophysical survey beforehand. However, the clarity of the results aptly demonstrates that a "blind" approach (lacking prior knowledge about a site) would work well for a much larger area of historical interest involving buried nineteenth-century stone foundations, such as in Nauvoo, located along the Mississippi River flood plain in Illinois, or in Church historic sites near Kirtland, Ohio. Our study of Provo's first tabernacle site demonstrates the utility of GPR for delineating both the basic outline as well as important geometrical details of the buried building. These include the thickness of the old stone walls, areas where a wall may be missing, locations of entrances, depth to the base of the structure, internal partitions or rooms, and information about materials (stone rubble, for example) that were more concentrated in some areas than others. The GPR maps also reveal the varying conditions of the remaining foundations—some areas have fully intact walls, whereas others show where stonework was removed or had eroded (see parts of structure depicted in grid 3). The ability to achieve such fine detail noninvasively provides developers with precise images that they may use to help decide the ultimate disposition of the archaeological remains. Determining the exact location of the first tabernacle helped the LDS Church make informed decisions concerning the construction of the new temple. In a general sense, knowing where areas of thick and deeply entrenched stone walls are located would guide construction efforts for any historic site undergoing development. The ultimate utility of the GPR results is to contribute to a lasting record of the 3D outline and internal structure of the site that will serve as a permanent resource for future archaeological and architectural study of this historic pioneer building.[9]

The authors can be reached via email at byustudies@byu.edu.

John H. McBride is with the Department of Geological Sciences at Brigham Young University. He holds a PhD from Cornell University and has an interest in applying geophysical techniques to the study of Mormon historical sites.

Benjamin C. Pykles is a historic sites curator for the Church History Department of The Church of Jesus Christ of Latter-day Saints. He has a PhD in anthropology (emphasis in historical archaeology) from the University of Pennsylvania and is the author of *Excavating Nauvoo: The Mormons and the Rise of Historical Archaeology in America,* published by the University of Nebraska Press in 2010.

Emily Utt is a historic sites curator in the Church History Department of The Church of Jesus Christ of Latter-day Saints. She is currently enrolled in Goucher College's historic preservation program, where she is writing a thesis on post-fire preservation of historic structures.

R. William Keach II is a research scientist with a focus on 3D visualization of geophysical data, with over twenty-five years' experience as a petroleum geophysicist. He splits his time between the Energy and Geoscience Institute at the University of Utah and Brigham Young University. He received a master's degree in geophysics from Cornell University and a bachelor's degree in geology from Brigham Young University.

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1. "The Provo Meeting House," *Millennial Star* 29, October 19, 1867, 661.

2. J. Milsom, *Field Geophysics,* 3d ed. (Chichester, West Sussex, England: Wiley, 2003), 169.

3. Once a relatively shallow target, such as a buried stone foundation, is located on a GPR image, it is common practice to dig a small test pit exposing the target in order to compare its depth with its measured travel time to and from the antenna. This allows the geophysicist to readily compute the velocity of electromagnetic radiation, as well as the "dielectric constant" (an electrical property related to reflectivity) for the ground medium between the top of the target and the ground surface. For the test pit dug over the southwestern corner of the first tabernacle foundation, a depth below ground surface of 16 in. (40.6 cm) was observed. When we compare this depth with an observed travel time of 8–10 ns, we can obtain the velocity of

radiation in the medium by dividing depth by time (remembering to divide the "round-trip" travel time by two) and then obtain the dielectric constant from the simple formula: $V_m = c/\sqrt{\varepsilon}$, where V_m is the speed of the radiation in the medium, c is the speed of light in a vacuum, and ε is the dielectric constant. This exercise provides a $V_m \approx 0.3$ ft./ns (0.09 m/ns) and $\varepsilon \approx 11$, values typical for moist silty soils. Assuming that the ground conditions do not vary significantly across the survey area, we can now convert all GPR travel time observations to depth below ground surface. For further background information on GPR fundamentals, see A. P. Annan, "Electromagnetic Principles of Ground-Penetrating Radar," in *Ground Penetrating Radar Theory and Applications*, ed. H. M. Jol (Amsterdam: Elsevier Science, 2009), 4–40.

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6. C. L. Richard, B. C. Pykles, and J. H. McBride, "Applicability of Ground Penetrating Radar and Geographic Information Systems for Documenting and Visualizing Historic Mormon Nauvoo, Illinois," paper presented at Annual Meeting of the Society for Historical Archaeology, 2010, Amelia Island, Florida.

7. 1888, sheet 4, Western Americana Division, Special Collections, J. Willard Marriott Library, University of Utah, Salt Lake City. Online documentation on the Sanborn Fire Insurance maps for Provo and other cities in Utah can be found at http://www.lib.utah.edu/digital/sanborn/.

8. For further reading on processing and display of reflection data, see R. E. Sheriff and L. P. Geldart, *Exploration Seismology,* 2d ed. (Cambridge, UK: Cambridge University Press, 1995).

9. Digital maps and original data files will be housed at the Church History Library, The Church of Jesus Christ of Latter-day Saints, Salt Lake City.