Dawn Johnson: Welcome to the Museum of Natural History Science Cafe. Thank you all so much for joining us this evening and for supporting this program. I'd also like to thank Conor O'Neill's who takes such good care of us while we're here, and who has been a long-time host and sponsor of this program. Yes.

[Applause]

Dawn Johnson: I'd also like to thank Kira Berman, Madeleine Zerrill 00:00:24, and Nora Weber who make this program possible.

[Applause]

Dawn Johnson: And our speakers this evening, Adam Rountrey and Nic Terrenato. Thank you for joining us. A couple of updates from the museum. We just opened our new exhibition, "Dinosaur Discoveries, Ancient Fossils, New Ideas." This is a travelling exhibition that came to us from the American Museum of Natural History. They organized it, and it will be on view at the museum through September 15th. We did our grand public opening this weekend and saw over 3,300 people. It was fantastic. Great outcomes. If you have not come to see the exhibition, please come visit it. We also opened our summer camp today, registration for members. On Friday at noon we open to the public, and that's already going gangbusters, so we're really excited about that. That's a big summer program for us.

We have three Scientist Spotlights coming up in March, two of them at the Museum of Natural History, and one at the Ypsilanti District Library. All of those dates and information can be found on our website. Again, thank you all so much for being here and for supporting us. As Kira mentioned, we have QR codes on the table if you'd like to give a donation, as well as the box in the back. Thank you so much for being here.

Kira Berman: Thank you, Dawn.

Dawn Johnson: You thank yourself.

[Laughter]

Kira Berman: Dawn, by the way, is our acting director, and we're very grateful to her for being here. I hope you have time to talk with her. I am Kira

Berman, and I coordinate the science cafes, and you're welcome to come in and sit anywhere you like. I'm especially excited about tonight's science cafe which is called, "High-Tech Bones and Buildings." One of the reasons I'm excited is that in my role in the museum world, I am always hearing and reading articles about this object, a copy was put on in an exhibit, and it was a 3D copy, and, you know, nobody could tell the difference. Or this object should be sent back to where it came from. Or this other object, we couldn't purchase a Majungasaurus tooth recently because it was from a different country, so you can't buy something that comes from overseas apparently.

Lots of different things. It touches me personally. I am particularly excited. Our two guests have been very generous, and they both are very accomplished in representing objects three-dimensionally. I will introduce them briefly. First I'll introduce Adam Rountrey, who is a research museum collection manager and 3D specialist at the University of Michigan Museum of Paleontology. I've known him for a long time. He has been involved with acquisition, analysis, visualization, preservation, and dissemination of 3D specimen data at this institution since 2004. That is a long time.

[Laughter]

Kira Berman: During this time, Adam developed the photogrammetry workflows—I don't even know what a photogrammetry workflow is, so you're gonna have to explain that—and 3D web viewer for the University of Michigan online repository of fossils. If you wanna see the online repository of fossils, just google, "UMORF," U-M-O-R-F, and you can find it. He currently manages that online repository. He is a co-PI on the Institute for a Museum and Library Services-funded project called, "Community Standards for 3D Data Preservation." Adam is particularly interested in issues related to rights and ownership of 3D data in museum settings. Thank you for being here, Adam.

[Applause]

[Pause 00:04:33 - 00:04:41]

Kira Berman: I also wanna introduce Nic Terrenato. He's the Esther B. Van Deman Collegiate Professor of Roman Studies at the University of Michigan. Since 2020, he also directs the Kelsey Museum of

Archeology. He studied at Rome and Pisa, and he specializes in First-Millennium BCE Italy, in particular Early Rome, Northern Eritrea, and the Roman Conquest. He directs the Gabii Project and the Sant'Omobono project, and his other interests include theories of state and empire formation, field survey and history of archeology. He recently published *The Early Roman Expansion into Italy*, which was awarded the 2021 Wiseman Book Award by the Archeological Institute of America. Please welcome Nic Terrenato.

[Applause]

Kira Berman: Without further ado, I am gonna turn this over to Adam. Adam, the yellow mic should be the one you use.

Adam Rountrey: Testing, testing. Okay.

Kira Berman: Awesome.

Dawn Johnson: Go for it.

Adam Rountrey: Cool. I think I'm gonna go to that end of the room so that you don't have to look back-and-forth between the table and the screen while I'm talking.

Female Voice: Thank you.

Adam Rountrey: Hopefully that saves your neck some stress.

[Pause 00:05:59 - 00:06:06]

Adam Rountrey: Okay. Thanks, Kira. Welcome to the Science Cafe. We're gonna be talking about digital 3D data. Kira's introduced me, so you know who I am and where I'm working, so I'll just go straight into it with talking about what it is we're talking about: digital 3D data. You can break up digital 3D data into two large categories. One of them would be 3D point or mesh data. An example of that would be the Volkswagen frame over here. That consists of three-dimensional coordinates, so X-Y-Z coordinates, like you can see up in this text file here, that are sometimes connected by edges or interfaces. That's what this part is down here. That is just saying which points get connected in this model to make the Volkswagen.

We get information about surfaces using this type of data, and we could get that from photogrammetry, which I'll talk more about later, but that's taking lots of photos at different angles; laser scanning; structured light; or sources-base, so that means like a series of measurements in a publication that we might turn into a digital model. Then, of course, there are creative, three-dimensional digital arts as well. The other category would be volumetric data. This is volume, so like an array, a three-dimensional array, or a grid, the kind of data that you get from a computer tomography X-ray scan, where we're seeing surface data as well as information about inside of the object we're scanning. Then voxel art is the creative side of volumetric data.

For the rest of my part of the talk, I'm gonna give a little history of digital 3D, how we do 3D capture of some natural objects, some applications within natural history, and then some questions or impacts or things that we might wanna think about when working with 3D data. For the history, I'm gonna go way back.

[Laughter]

Adam Rountrey: Digital 3D data is interesting in its dependence on computer visualization. Right? That series of X-Y-Z coordinates that I showed you on one of the earlier slides is very hard for us to interpret. It wasn't until we got to the beginnings of visualization with computers, interactive visualization with computers, that we could start to think about working with 3D digital data in a broad context. Taking it back to 1961, Ivan Sutherland was working at MIT on his dissertation, and in '61 and '62 developed the first interactive visualization system for computers called, "Sketchpad." It was pretty remarkable. Some people were saying that this system should basically emulate what happens when we draw on paper, so we should be able to draw lines, and they shouldn't move. *[Laughter]*

Sutherland took a different approach, and along the way invented a bunch of things that are super common in so many graphical-user interfaces today. The idea of a rubber band line, where you click a point and then click another point and make a line that can move, was developed in Sketchpad, as well as copy-and-paste of geometric instances, and Zoom, which is a big one. This was ground-breaking work that was in his dissertation in 1963. At the same time Larry Roberts, who was a major part of the foundation of the internet through ARPANET, was also at MIT and did the first three-dimensional renderings on a computer, which are shown here in this panel from his dissertation.

He had to deal with a few problems with thinking about what humans need to understand 3D objects in this sort of visualization. One of them was perspective, which is pretty obvious. The other one is occlusion. If you look at this table model, the top of the table there blocks your view of the legs behind it. It turns out that's really important for humans to understand what's going on with 3D structures when they are projected in the TV like this.

Then pretty soon after that, we started getting shaded renderings, like this cube over here by Chris Wiley, who was working at the University of Utah. He is also the person who pushed this idea that we should represent complex geometry using a series of triangles because it's computationally efficient, which is how we do it nowadays. I have a fun little video that someone can click on for me here. This is a demonstration of Sketchpad. That's Sutherland operating it. There is the rubber band line, it's first appearance.

[Laughter]

Adam Rountrey: Completely different than how we interact with paper, and it changed how digital design would work over the next few decades. *[Unintelligible 00:11:41]* tracking. This is one of Larry Robert's models. The frame rate is super slow. That is moving.

[Laughter]

Adam Rountrey: This one's a little faster. That's the first rendering of digital data on a computer. Okay. Moving along and getting more complex, the first digitized, natural object that was then rendered back in a computer is the face of Sylvie Gouraud, who was the wife of Henri Gouraud working at University of Utah with Ivan Sutherland. He was working on some smooth-shading algorithms, but this digitization of her face has about 60 polygons in it, so a pretty low complexity still in 1971. Then this Volkswagen, which might look familiar from an earlier slide, was a famous example that was used as demonstration data for a long time. That's about 2,000 polygons in that model.

I'm gonna jump ahead a few decades to the late 1990s. This digital Michaelangelo project that came out of Stanford by Marc Levoy, I consider this one of the first attempts to make research-grade, three-dimensional data that represents real objects. "Research-grade" meaning that it could act as a substitute for scientific or historic research on the actual objects. The goal here—it sounds like a fun time—they got a bunch of grad students, staff and faculty, and went to Italy for the '98-'99 academic year with the goal of scanning as many sculptures of Michealangelo as they could in the time. They had also this goal of capturing the geometry of the chisel marks.

In order for these to be replicas of the actual statues, and for researchers to be able to study the types of chisels that were used, or the orientations, they needed to capture those. For that, they needed a resolution of about 250 microns on some statues like David that are gigantic. It was a pretty huge undertaking. They had a custom laser-line scanner that was developed by a cyberware, and they spent over a thousand hours scanning 10 statues, and then 1,500 hours post-processing. They put a lot of effort into this, and the data are amazing. They're still amazing today. This statue of Saint Matthew here, which you can maybe see the chisel marks on, that's about 400 million faces, so way beyond where we were with Sutherland's Volkswagen.

Immediately, at the end of this project, they started hitting some of the problems that we're still facing today with 3D data. They had 500 gigabytes of data, which doesn't sound super scary today, but I think the prices then were six-dollar-a gigabyte for hard drive storage, and so it was thousands of dollars just to have the hard drives to keep the data.

They also ran into issues with rights and licensing, so they had contracts with government in Italy that they could only release data for research and educational uses. I guess maybe there was some penalties involved in that contract. They were really nervous about the data getting out and getting used for commercial purposes because they were the best representations, digital representations of these statues. Go forward a couple of years. That's me in the early 2000s digitizing a Mastodon ulna with my PhD supervisor Dan Fisher. Hey, Dan.

[Laughter]

Adam Rountrey: That's a point digitizer, so we're placing the probe on the bone to take every point that will be in that model, which will be a few thousand points. It was a long, long process, but eventually we did succeed in Dan's vision of an articulated, digital Mastodon skeleton, which you can see on our UMORF website. Things really changed in 2011 and 2012. It was three different things that happened that really accelerated 3D data acquisition across research and education.

That was the GPU revolution, so we got much faster GPUs. We had photogrammetry algorithms, so photos to 3D, that could take advantage of those fast GPUs and run things in parallel. Then the WebGL spec came out in 2011. That was a way of displaying and interacting with 3D data on the web. All of these things happened right around the same time in 2012. Nowadays anyone with a camera can produce research-grade 3D data on a camera and a computer.

Let's see. Okay. Kira can start this for me in a second. This is a video that just shows the process of photogrammetry. We've taken a bunch of photos all around this part.

Female Voice: *[Unintelligible 00:17:20]*

Adam Rountrey: Sorry?

Female Voice: *[Unintelligible 00:17:23]*

Adam Rountrey: Sure. This part of an Entelodont skull. This isn't the software we used for production work, but it shows the process a little better. It's going through right now and looking for features in all of these photos. Then it's going to do pairwise matching of features between every possible set of photos. I'll show you an example here in a second of feature-matching. Those are the corresponding features on two of those images, and it has that information for all possible pairs. That was a real-time calculation.

Now it's gonna use all of those feature matches to calculate the position of the camera for each photo, the lens distortion, and the positions of those features on the object. That "sparse point cloud," we call it— it's not very good there—that's used as the basis for some additional algorithms to compute the full-resolution, 3D model. Once we have all of this 3D data, what can we do with it in natural history? Maybe the obvious one is it makes these things much more accessible. Right? Here is a student doing a scan. Well, I call it "scan" because "photo-grammetrize" is not a great verb.

[Laughter]

Adam Rountrey: The Owosso Mastodon skull, which is on display at the Museum of Natural History, this would be a difficult specimen for someone in another location to work on—right?—so they'd either have to come here and close the exhibit and work on it, or we'd have to take it off-display and ship it to them in a crate, which would be expensive and time-consuming, and a risk for the specimen. That's the obvious accessibility issue. It also enables some other kinds of research. We could do a study where, say, we're looking at the shapes of skulls through time, as, say in the evolution of horses or something, using some landmarks and to track that change of shape through morphometrics. That's a pretty common application for 3D data of this kind.

We can also do biomechanical modelling. This is a cool study here of some fossil and modern carnivorens with different killing strategies imposed on their skulls. It's showing the distribution of stresses on the skulls with different actions, like stabbing, or pulling the teeth back, or a side-to-side shake like your dog might do with a toy. I don't have time to go through these, even though it's really interesting, but I'll point out that this one, so Smilodon, the Saber Tooth, is not good at lateral shaking. Right? There's a lot of stress in the sides of the skulls, and in the teeth, so the skull is not designed to do that sort of thrashing. It's well designed for strong stabbing and biting. I wish I could go through the others 'cause it's really interesting, but time.

There are educational uses for 3D data. During the move from the Ruthland Building to the current home of the Natural History Museum, we scanned a bunch of the old exhibits, including the "Life Through the Ages" dioramas. If you can click on that? These are all available on our UMORF website. There's the URL at the bottom. This is me scrolling through the dioramas. Part of this work was done during COVID to make these things accessible for teaching during the time that things were shut down.

We actually had a student go through and add these little labels, which will get clicked on in a moment, but you can click on those. It tells you what the organism is, and sometimes has a link to a 3D model of the actual fossil rather than the reconstruction. In addition to educational use, they are a historic preservation because these things are no longer on-exhibit, at least in that fashion, so we have some record of how they were in the Ruthland Building.

I talked a lot earlier about visualizations and how important it was, but we can also have physical interactions with the digital data through 3D prints. Some for exhibits. Here's the Bristle Mammoth with 3D printed tusks because the actual tusks were too fragile and heavy to use in the display. We can also play around with size. In this picture down here, that's Maiacetus, Dorudon, and a modern-day pilot whale. Yeah. There's the Maiacetus. They're all at half-scale, which makes them much easier for kids to handle.

We sent a set of these out to the Perkins School for the Blind in Massachusetts for a touch lesson on evolution of whales, which I think is a pretty cool application for the 3D print. Then this example over here, once we have 3D prints, we can also turn them into robots. This is a cool study, where this coiled, shelled, cephalopod had a water pump installed, and the swimming behavior was studied to understand the hydrodynamics of it.

Okay. I'm probably over time, but I wanna end with some questions, or things to think about. One of them with 3D data is authenticity, so it's really easy to create and modify 3D data, and it's pretty hard to track that. What are some ways that we can think of maybe that we can verify that we have a good copy? Or what are some practices that we should use to know the quality of the data that we're using? Especially for research and education.

There are a bunch of issues around the ethics of 3D capture. Accessibility, so we're trying to make these things more accessible. We are making them more accessible, but we're also widening the digital divide. Right? There are some places where even though we put this online, and you don't have to download anything, it's still not accessible. Should we consider archived, digital 3D data as permanent? Is this a way or preserving things long-term?

Then this one, I like. It's interesting to me. This research logistics and context. We're getting fewer visitors to research museums now, and we're sending out fewer loans because we're sharing digital 3D data of our specimens which is suitable for their research. Now they're looking at that three-dimensional model on a computer screen, perhaps in isolation, and they're not looking at it in the drawer surrounded by a million other specimens. How does that change the kinds of research questions that people are asking? Then my favorite one has to do with licensing and access control on these models. I'll stop there and not talk about Nefertiti unless we have time later, so I'll end there.

[Laughter]

Dawn Johnson: Yeah?

Adam Rountrey: Good?

Dawn Johnson: That's great. Thank you.

Adam Rountrey: All right. Thank you.

[Applause]

Nic Terrenato: Good evening, everyone. I'm gonna talk about the applications in archeology, which in many ways are very similar to those in paleontology. The key thing here is that there are two basic applications or groups of applications. One has to do with archeological objects, like the ones that we have in our museum. The other has to do with archeological sites. You know? With their complex stratification and their remains, the architecture, and so on and so forth. It's, among other things, a matter of scale because, of course, with sites, you're talking about, you know, you're in the yard range, and with most objects you are in the centimeter range.

What happens is that building off of what Adam was saying, the technology that was being used, especially for these sort of macro-environmental reconstructions and 3D modelling, it used to be very cumbersome. When we started our excavation in Italy in 2009, we would take all of these pictures of a certain archeological feature, and then we would feed those to a fairly powerful gaming computer. The gaming computer would think for an entire weekend, and then Monday we would get the 3D model. This has changed enormously. You know? Better algorithms, better graphic processors, as Adam was saying, but also the interesting integration of laser and photogrammetry.

The two systems that Adam was referring to were—you know? With photogrammetry, you are trying to teach the computer about perspective and to figure out where all of the pictures are taken. With laser, you are actually shooting a laser beam and measuring how long it takes for it to bounce back to the camera. At this point in the last couple of years, even a relatively simple thing like an iPad and iPad Pro is equipped with, well, essentially with a laser, we call it a "LiDAR" camera. Here, you can see here these two are the photographic cameras of the iPad. This little white dot here is the LiDAR camera. When this iPad takes a picture, it's both taking a picture and also shooting laser beams and measuring the distance. This speeds up the process enormously, and so to the point where I can actually demonstrate it for you right here.

This is we are pointing to camera at this corner of the room. You know? You define the range. You start shooting, and the hashed areas are the parts where there isn't enough information yet. Of course, you can see that you need to go around so that you will get all of the parts that are otherwise covered. For instance, in order for us to get a really good sense of what's behind us, a skull, we would have to squeeze the camera behind it, which at this point is not practical. Essentially the more photographs that you have, the more images you have of this, the better and the more, the clearer the image is gonna be eventually. For instance, here we can stop here for a second. You see there is already, we have a mock-up of the corner of the room. Then we say that this is an "area," and, well, you can time it. It's gonna take less than 30 seconds probably.

Dawn Johnson: We did ask Adam if we could scan this, *[unintelligible 00:28:38]*.

[Laughter]

Nic Terrenato: Yes. Yes. We have permission to scan the whale. This is what you get.

[Pause 00:29:47 - 00:29:52]

Nic Terrenato: Where you can see that the geometry of it is very much there. Once again, if you try to go—well, now there are some problems. See, for instance, here.

Female Voice: *[Laughter]*

Female Voice: Yeah.

Nic Terrenato: Those two lines, really that should line up together. Keep in mind that I only shot this very briefly just to give a little context. If you do this more accurately? You see, for instance, here there is what we call a "hole" at the back of the skull because there wasn't enough information to reconstruct. If you try to imagine that as a 3D solid, there's gonna be a hole in there. You can easily see the incredible ease and application of this, so you can very quickly produce three-dimensional scans. It really works best with this kind of distance. You know? In the five-meter range.

If you try to go to the shorter range for a smaller object, actually the LiDAR camera isn't as effective as the rest, as in other situations. Generally you have really this incredible ability. With just a few iPads on my excavation, we can document any number of layers or walls or floors or tombs or whatever just by and essentially waving an iPad. You know? It used to be a high-tech operation, and now it is something that within certain parameters even an undergraduate can learn how to do in a day or two.

[Laughter]

Nic Terrenato: Yeah. Which is very important for us. At this point we gather something in a five-week season in the field. We probably do something in the order of 500 3D models. You know? You can do the math. It's like a couple of dozen of 3D models every day that we are in the field. Of course this creates then the problem of how you handle this massive data. It's still true that if you generate all of these 3D models at an adequate scale, you need a lot of storage, and you need a lot of, more than anything else, an ability to make this accessible, both to the scholarly community, but also to the more general public. Unless you guys want to see more demonstrations of this—or we can even do that later, if anyone is interested—I was gonna shift to showing how we do online publications of our archeological data. This is also gonna take just a quick second. Bear with me while I log in 'cause it's a different computer.

Dawn Johnson: It's the HDMI? Yeah. There we go.

Nic Terrenato: You got it?

Dawn Johnson: Yep.

Nic Terrenato: Good. This is the end result of the process. I'm now, of course, speeding up things a lot here. Through Michigan University Press, we can combine all of this information that we've gathered in the field and present it in online volumes because, of course, you can never do this in a paper volume because there is no way that you can present, or any 3D model in 2D would lose most of its effectiveness so that it has to be online. We already have two of these volumes out, and they are open access. Of course, as Adam was saying, this doesn't entirely level the playing field because you still need a relatively powerful computer to access them, but we also publish low-res versions, and text-only versions, that of course, don't have all of the functionality, but at least have all of the textual information.

I just wanted to show you how this works. For instance, in this particular volume that is presenting a house from about 2,300 years ago, we have all of these 3D models that have been put together. We have them all in the same space. This allows you to investigate this excavation, almost as if you were digging it all over again. Of course, you have a text here on the left that describes what you find, and—this is what turned out to be quite complicated to do—you have a system of hyperlinks that goes from the text to the 3D model 'cause it's relatively easy to go from the 3D model to the text, but the other way around, it's a bit more complicated. In this way, the 3D model becomes a table of contents of the archeological publication.

This really changes the nature entirely of how we publish, and we disseminate information about archeology. Here we have our house. Of course, as you can see, some of its features are very modeled in very great detail, and they can be highlighted, and this will take you to a database that has all of the relevant information. Also, you can turn on all of the various, for instance, reconstruction if you want to see what we think the house looked like in various periods, as well as all of the various layers of soil that exist and were deposited at various times. This, which came out about five or six years ago, really, we think, marks the future of the publication of archeological data, but also many other kinds of data that have this spatial component.

Whenever you really need to show a relationship between a three-dimensional space and the information that is attached to it, you need something of this kind. Just to close and show this is the other publication, which is primarily a graveyard, and I wanted to show you here briefly how this really allows you to almost reproduce the excavation as it happened. This is the tomb of we later learned of a woman. Of course, when we're at this level, we can only see a cut in the ground, and we so we do a photogrammetry of the top. Then, if you remove it, you see the photogrammetry of what we found underneath, which is a very strange burial with sheets of lead that are abutting one another and covering tiles. This is the lead. When you remove the lead sheet, you see the tiles that are still covering the body.

Of course, all of these things are in full 3D. For instance, this allows, as Adam was saying, all sorts of scientific approaches. For instance, we can calculate the volume of the lead and know how much lead was required for this kind of burial. Then the cover is removed, and you have the skeleton that is lying on another sheet of lead, which is also very unusual. Then you remove the skeleton, you have the sheet of lead on the bottom, you remove that, and then you are left with just the cut of the tomb. This is what the tomb looked like when they first dug the grave.

This kind of ability to really reconstruct the whole sequence of events and to see its relationship in a three-dimensional space—because you see here you can really see how all of the different layers are coming together, and they are combining together—is a level of archeological knowledge that we really never had because, where we were relying on cross-sections and other 2D attempts, you know, which now seem quite feeble at representing a very complex, three-dimensional object.

This is the macro part. Very quickly as a way to introduce also our discussion and our conversation, when it comes to smaller objects, portable objects, which in the case of archeology, but that's true of paleontology as well, often have a material value because objects that are found have a market. The ability to 3D-scan these objects in the same way that we scan archeological sites creates a different landscape in any number of ways. Of course, from the research point of view, again as Adam was saying, there are all sorts of things that we can do that we weren't normally able to do on these objects.

Also, in fields like paleontology and archeology that have been dominated by what I like to call the "fetishism" of the original object, the idea that the original object has a special value, a value that nothing else has, which is sometimes founded in realities, and sometimes it's quite fictional in a way. The ability to document these objects and the ability to reproduce them, depending on the situation, in very great detail really changes the terms of and the nature of the question.

Issues that, you know, we have in the questions about the Elgin Marbles, the marbles that were taken from the Parthenon in Athens to the British Museum in London, of course. That nature of that very controversial, very thorny, political and diplomatic question are changed by the affordances of 3D scanning because now there are all sorts of things that are possible in terms of the documentation, in terms of copies that weren't possible before. Thank you.

[Applause]

[Pause 00:41:35 - 00:41:42]

Kira Berman: Thank you so much to both of our speakers. Sorry for yelling into the mic. Thanks so much to both of our speakers. We'll take a break now for a few minutes to let you discuss what you've heard. There are some materials on your tables. You can also visit with our wonderful wait staff here at Conor's and order something else to drink, should you like, and we'll come back in just a few minutes for a group conversation, and you can ask your questions.

I'm gonna try to interrupt your conversations—it's always my least favorite part—and bring us back to the center of the room. At this point we're going to start a group conversation. It's gonna give you a chance to ask some questions, both of each other and of our speakers. Before we start that, I have a few ground rules that I usually read. Those of you who have been here for many science cafes will recognize them, so they shouldn't come as any great surprise. I have agreed to moderate, and I will let speakers know when they have the floor, and when they don't.

[Laughter]

Kira Berman: I will pass this cordless mic, and I'm gonna ask you to use it to enable those with hearing impairments to hear, and also because we are recording our conversation for a later podcast, and you wanna be heard clearly on that. Please look at me to be recognized if you would like to speak, even though I am not an expert in 3D technology. That's the understatement of the year.

[Laughter]

Kira Berman: Please limit your questions or comments to around 30 seconds to a minute so that lots of people can participate. There was a lot of issues here about objects and returning them. I heard conversations about the Elgin Marbles. I heard conversations about lots of different kinds of access, so please ask those questions. I think there are a lot of questions in the room. I always hope that this part will feel more like a group discussion rather than just a Q&A session.

There is lots of expertise and experience in the room. I'm looking at Dan, *[laughter]* but lots of other expertise and experience as well. With this in mind, please feel free to address comments as well as questions to the group to ask other participants for their experiences, *et cetera*. We like to foster open discussion and honest debate, even as we address topics about which we might disagree, so please be nice to each other, or else.

[Laughter]

Kira Berman: If you forget to turn off your cell phone, and it rings during this portion of the program, we promise to 3D-scan you as you drink your beer.

[Laughter]

Kira Berman: Don't make us do that. Please silence your phone. All right. Does anybody want to start us out with a question, comment, observation?

[Pause 00:45:02 - 00:45:07]

Audience Member 1: A number of years back, before the museum moved to its new location, there was a visitor that came from the Royal Veterinary College and gave a talk about how fast a T-Rex can run. He actually estimated that it was somewhere in the neighborhood of the speed of an Indian elephant. Does this kind of looking at a skeletal structures and the like reveal any information about how fast such an animal could run, and the like?

Kira Berman: I'm gonna take this before I let them answer and say you have to come see our new exhibit called, "Dinosaur Discoveries," which addresses exactly that question in exactly that way. Now you guys can answer.

[Laughter]

Adam Rountrey: Well, now I'm on-the-spot because I haven't come to see the exhibit yet.

[Laughter]

Adam Rountrey: I guess, yeah, running speed is one of those things where biomechanical models can come into play. The example that I showed with the stress distribution on skulls, similar things can be done with limb bones, and we can estimate what kind of stress a bone like that could take given the distribution of cortical and trabecular bone. We can come up with ideas of the maximum speed or the maximum stresses that could be on a limb, as well as there is musculoskeletal modelling to think about lever arms and how much force could come into the running process. Go see the exhibit, I guess, I'd say.

[Laughter]

[Pause 00:47:00 - 00:47:08]

Audience Member 2: I recall reading about a technology that was applied to monolithic structures and civilizations in Central and South America that used some kind of radar device from helicopters that evaluates what's under the ground 50 feet deep. Does that present possibilities for your work and 3D modelling of such monoliths?

Nic Terrenato: Oh, thank you. Yes. As a matter of fact, there is a handout on your table on that exact thing. The big sheet. Yes. This LiDAR that I was mentioning briefly, one of its many applications is that at certain frequencies, it will go through softer elements, such as vegetation. Whereas you can do a three-dimensional modelling of the landscape from any kind of a drone or helicopter or a plane, when you are in heavily forested areas, like in the rainforests of Central America, you're only gonna see the top of the trees. With LiDAR instead, you get—once again, if set in the right way—the signal will bounce off the first hard objects it encounters, so it goes through the vegetation, and then back up to the sensor.

This allows the creation of three-dimensional maps from the air that will reveal the geometry of the actual landscape under the vegetation. In certain situations, for instance, Maya Pyramids have such a distinctive geometry that if you see something that is stepped and square, you know that that's a Maya Pyramid, and it's lying deep under this forest coverage. This is also being used in Europe a lot with medieval castles. There are a lot of medieval castles that are completely covered by vegetation, and you can see them because they will have towers and crenellations and the obvious medieval stuff. Yes. That is also revolutionizing, especially in those areas where there is vegetation cover.

Kira Berman: I think part of the question was also about ground penetration. Is there technology that can do that?

Nic Terrenato: Yeah. Then for that you use radar, but that has to happen really on the ground. I am not aware of any radar, ground-penetrating radar rays that are operated from a flying vector. Yes. You drag a radar ray on the surface, but that's typically not in forested areas but on, for instance, cultivated fields, and this will produce a stratigraphy of what's buried under the ground. That is, for now, it is a much slower technique. You know? It will take a couple of days to cover an acre. Whereas with LiDAR, you can do square miles in a day.

Kira Berman: Adam, did you have anything to add before we move on? Okay.

Audience Member 3: Hello. Thank you for your presentation. Very interesting. I can see many uses for this technology. I was wondering to what extent you've used it in medicine. So, for example, when a person is about to have an amputation, to what extent can you take the model of the given leg that will be amputated so that that leg, the shape and all of the characteristics can be recreated with the new prosthetic?

Nic Terrenato: Well, neither of us are doctors, but I do happen to know that definitely this 3D technology is used a lot in cosmetic surgery, where they do a 3D scan of your face. Then they say, “Okay. If we puff up the cheekbone a little bit, this is what you’re gonna look like...” I don’t know. “If you implant some hair, *[laughter]* this is what you’re gonna look like…” They use it to mostly sell their services. I am sure there are many other applications.

[Pause 00:52:00 - 00:52:06]

Audience Member 4: Okay. We had a lot talk about the Elgin Marbles. I just wanna get your view on this. Since they’re stolen objects, why are the British so hesitant to let people scan them?

Nic Terrenato: Yeah. That’s a really good question. Well, as we were saying in the questions that you have on the table, there is this controversial issue that the British Museum will not 3D scans of these marbles, nor will it allow people, other researchers to do it. There is this, you know, like with Nefertiti, there are these guerilla tactics of going into the museum and taking a bunch of pictures, or taking one of those iPads and trying to produce models that are as accurate as possible. I think you were showing it was that, the difference between a guerilla model and the unofficial one, the map algebra that you were showing.

Audience Member 4: It was. Yeah. Yeah.

Nic Terrenato: Yeah.

Kira Berman: Do you wanna talk about that?

Adam Rountrey: I can. Yeah. The image that I closed the presentation with was a mesh distance calculation for the Nefertiti Hack model, which is the one that was supposedly done with a Microsoft Connect, so there’s a video of these guys running in and waving the Connect around. The quality of the scans produced by that device: not good. The scan that they actually released was very high quality, and so immediately people were saying there is no way that they made it that way.

The distance there shows that it's within about a millimeter of the model that was finally released through a Freedom of Information Act equivalent, and it's definitely a different scan. It is a high-quality scan. I think it is a CT scan that was done earlier that someone got on a thumb drive, or somehow got from the museum, rather than what they said it was with this guerilla attack.

Nic Terrenato: Of course, the British Museum will not say why they have this policy, but people are thinking that since you can now have—not only you can 3D-print up a 3D model, but there are sculpting machines that can actually chisel the actual stone to fit a certain 3D model. That someone might do that, and on using the same-exact marble that was used for the Parthenon, which is still available, and show it to the British Museum and say, "Here. This is an identical copy of what you have.

Why will you not return the original?" Right? They don't wanna be embarrassed. The supposition is that they don't wanna be embarrassed in this way by somebody showing up with something that it's such a close approximation of what they have that then it becomes hard for them to hang on to these things.

I will say having some friends in the BM that they would dispute that they are stolen because they were taken from Athens with a regular permit way back when. That is a historical fact. The Greeks, of course, countered that. This was the Ottoman government that authorized them and that had no true cultural right to these objects. They weren't stolen as in under cover of night. This was done in the open.

Audience Member 5: In a related question on authenticity, as we have all seen just recently that AI can be given some instructions, and it can create pictures that are incredible, and that's what? It's only been out on the market for a year or something. Given the technology and where it's going, what is the scientific community going to do? Like for some of the things you demonstrated on that tomb. You know? Somebody else can just tweak something, create it, and so where is the real one? You know? Well, how will you be able to tell the difference? Nefertiti was a good example of one you could clearly tell from a quality standpoint that one's fake and one's better. *[Laughter]*

Nic Terrenato: Yeah. This would apply also to paleontology that you can create a fossil that doesn't really exist, and you can show a 3D scan of it and argue that you have it, and then the reality is just—yeah, no. I mean, standards of authenticity have become much more complicated than they used to be. You know? It's the same kind of revolution, when you think about it, that happened with audio tapes only a few decades ago because up until the fifties and sixties, an audiotape was a document because it was not easy to tamper with.

Then it became very easy to tamper with. Then now you have forensic audio guys who can tell. You know? I am sure that there will be a profession of the forensic 3D person, who from maybe the mesh or other small details, tries to tell something that has been scanned from an original to something that has been just created by AI or other means. Yeah. It's a really good point.

Adam Rountrey: Yeah. On the AI-3D-creation side, there have been models that are able to produce 3D objects for a few years now, and they're getting much better very quickly, just like everything else in AI. You know? There are systems where you can type in something like, "bear," and you get a 3D model of a bear. Or systems where you can give it one image, a single image of a scene, and it will create a 3D model of that scene. I think in terms of documentation, like from a science perspective, every time we publish something that has digital data associated with it, 3D data, that is deposited in a repository. It gets a DOI, so a unique identifier that's stable so that we can identify at least the ones that are used in publications, and they remain accessible.

I did have one other thought about AI 'cause I was thinking about the accessibility issues and where are we going with AI, so this is not part of your question but just a side comment, I guess. I was thinking about the visually impaired example, so using 3D-printed models to teach evolution, and thinking then about our dioramas and how could we make those accessible to people that are visually impaired because it's such a visually rich environment. It turns out that if you give images from the online viewer to a system like ChatGPT, it can describe the scene quite well, and tell you that, number one, "It is a shelled cephalopod," and where it is in the scene. There is a new way, I guess, of interacting with those models that could come about through AI.

Kira Berman: Cool. We have to do more with you, with those models of the old dioramas. That's awesome.

Adam Rountrey: Yeah. *[Laughter]*

Kira Berman: I also wanna add that if you go to the Natural History Museum in Venice, Italy—and you may know that the symbol of Venice is a winged lion—they have a fossil of a winged lion, but I don't think it was created with AI.

[Laughter]

Audience Member 6: I'm backtracking a little bit here, but there was a question about being used in medical. I recently had some caps put on my teeth. Rather than the usual implant with that gooey stuff, they put a camera in my mouth and scanned it. Nobody could tell me how it worked, but in my brain it was 3D imaging. They came back. They were perfect. They fit right away, and everything's great. They are using it for something there. *[Laughter]*

Kira Berman: There was a question. Oh.

Nic Terrenato: Can I just add?

Dawn Johnson: Yeah.

Nic Terrenato: That so much so that there is plenty of companies where you don't even have to go into their facility. You just send them pictures of your teeth. This is especially for orthodontics. You send them pictures of your teeth, and you get Invisalign *[unintelligible 01:01:18]* that will fit you. It works so well that you can do this online instead of going to the dentist and do the whole process. After x-number of weeks, they will send you the one that is modified a little, so they program the next one.

Male Voice: The next one. Yeah.

Female Voice: Oh, wow.

Nic Terrenato: They progressively, they will take to where you wanna be in terms of orthodontics.

Kira Berman: I wanna know more about that.

[Laughter]

Audience Member 7: In regard to the buildings and all, I would think that one of the nice benefits of having it scanned is that all of a sudden the sociologists can start looking at it and try to understand like, what was the human interface with this structure? Right? I mean, it's one thing to have the structure, but we really wanna know how it was used and maybe the activities and all. Right? Has that been flourishing more because of that, because of what you're doing? Or not?

Nic Terrenato: Yes. Absolutely. There is even a fancy word for it which is "archeological phenomenology." I mean, we have at least two graduate students who are writing, who have that as part of their dissertation right now. This is all about the lived experience of a monument. Instead of just, saying, looking at its geometry or artistic value, it's all about the experience. Other sensory things you can do. For instance, you can see how sound would bounce off the walls, and so what then would be the experience of, for instance, giving a speech in a certain political arena, or of an actor delivering a line in a theater, or a gladiator fighting in an amphitheater. Yes. Absolutely. This has opened the door to all of this sensory stuff that wasn't there before.

[Pause 01:03:15 - 01:03:21]

Kira Berman: One more?

Dawn Johnson: Possibly.

Audience Member 4: I think it's fascinating the possibility that if you scanned some tomb or something like that that I could go in with my Google Goggles, which I've never tried or done—but I can imagine it—and walk through there as a human experience, and actually see it and do that. My other observation is these LiDAR images here. It seems like you should be careful about letting those out because I am sure there's tomb raiders right there right now digging for stuff.

Nic Terrenato: Yes. Yes.

Audience Member 4: There is a way to thwart that if—I mean, everybody wants to monetize everything. If you scan all of this stuff, so you can make reproductions of it at will, at the cost of doing the reproductions, then it takes away the incentive to destroy things in order to—I mean, a lot of things get destroyed because the guy can chip off this little part of it he's got and sell it at the market at a markup. You know? I can understand the museum, the Elgin things, that's money for them. That's getting people in the door paying to get into that museum to see those things. That's the reason why they don't wanna give 'em up.

[Laughter]

Kira Berman: I think the British Museum's still free to go into.

Nic Terrenato: It's still free to go into. Yeah.

[Laughter]

Audience Member 4: It's pretty cool.

Kira Berman: Yeah. There is a question about the real objects. What do the real objects do that the reproductions do not do? For example, with some fossils that are relatively recent, we might be able to get DNA. You can't do that from a 3D print.

Nic Terrenato: Right.

[Sounds of agreement]

Kira Berman: You've got a mic.

Nic Terrenato: You know? Ultimately this is something that we're very familiar with because when you think about it, when somebody pays thousands, or tens of thousands, or however much, for a baseball ball that was hit by Babe Ruth, it's still a baseball. Okay?

[Laughter]

Nic Terrenato: You know? Its physical properties are really not changed. You actually have to believe that that is even correct because, you know, yeah, there might be Babe Ruth's signature on it, but, you know? That too can be faked very easily. I think that overall we tend to—that's where I was using the relatively heavy word, the "fetishism" in that we are creating fetishes of these objects because, not of a physical property because if you say, "Okay. A gold bar has a certain value because of what it is," but when the Babe Ruth baseball really has a value because of some sort of quasi-magical association that it has with a certain event in the past, and so people are willing to pay through their noses for that.

When it comes to certain materials, it's absolutely true. Especially statues, we really obsess about originals when the originals really can't tell us much more than the copies can. This is not always true. For instance, imagine a textile. A textile is something that you can still—the original textile contains a lot more information than any copies you can make because it has to do with—you know? There are all sorts of C-14 isotope studies that you can do on the original that you can't do on a copy.

When it comes to stone, stone is stone, so there is not much that even in the future, you can imagine, that you're gonna be able to do. In those cases, really it becomes this obsession that we have, and not just the public, but also the scholars and the politicians, with having the originals. In this, the Greeks and the Brits are exactly on the same page. They both want the originals, and they won't hear of having copies so much so that—you know? If you go to the Acropolis Museum in Athens, they have their original pieces. Then for the pieces that are in London, they have the crappiest casts you can possibly imagine.

[Laughter]

Nic Terrenato: Where you see drawn lines, and they're chipped. This is done on purpose because if they were to put up good casts, people would say, "You have the cast. Why do you need the originals?" Both are playing the same game. Both are playing the game of try not to have things that are too close to the original to go around because that detracts from their argument that the originals matter.

Adam Rountrey: Yeah. I guess I just wanna add from the research perspective. There is this commercial value that maybe started the question, but in terms of research value of paleontological specimens, I think having accessible 3D models may actually increase the value, the research value, of the specimens because they are much more accessible. There's a broad audience that knows they exist and what their general properties are. We get more requests to do the kinds of sampling, like you're talking about with radiocarbon dates or isotope-sampling, or something that you can't do from a copy, just because people now know that this thing exists and that it is what the thing they're looking for. Right? There is that interplay between the two.

[Pause 01:09:25 - 01:09:32]

Audience Member 5: I guess I have a paleontology question. I think about the bell curve. Like the people, like most people are in the middle, and you got the fringes. Right? I think about what you find holistically in the fossil record. Do you think you're finding the average? Do you think we're finding some poor, stupid duck that got stuck in the mud? There's only one that ever did it. You know what I mean? You know what I'm saying?

[Laughter]

Audience Member 5: What's the representation of the population? I mean, is that a thought in that space? Or not?

Adam Rountrey: Sure. Yeah. I think it's highly variable depending on the context. There are definitely catastrophic sites where there is a submarine mudslide that comes down and just completely covers everything that was living where it is; everything's preserved in place. There are other situations, tar pits are a good example, where it's not at all even sampling. Right? The tar pits have a much higher representation of carnivores because the herbivores are getting stuck there than we think actually existed. They are also biased toward feet, which is funny.

[Laughter]

Adam Rountrey: It depends very much on the context of burial, and then how things are getting in. When you average that over geologic time and Earth, I think we have a pretty good picture of what was going on from this combination of highly-detailed logger stat 01:11:11 in these excellent sites and samples elsewhere. Yeah.

Kira Berman: We often say when we're talking to children about fossilization that if you have the same number of jelly fish and the same number of turtles, you're probably gonna get more turtle fossils because hard stuff fossilizes more than squishy stuff.

[Laughter]

Kira Berman: I think we are at-time. I wanna very much thank our speakers. Thank you so much.

[Applause]

Kira Berman: I wanna direct your attention to the little yellow pencils and the little blue evaluations. Those are gonna help us in lots of different ways. One of the ways is that you can put ideas for future science cafes on those little blue evaluations, and we will find an expert. I heard a lot of you talking about AI. I want you to know I'm working on planning a science cafe on AI for April 24th. In the meantime, the next science cafe is on March 20th, and it will be on PFAF, or PFAs and water quality. One of the sponsors from the sponsoring organization is here, John Sullivan, so he'll be here. That's next month, March 20th. Thanks so much for coming out, everybody. Good night.

[Applause]

[Pause 01:12:45 - 01:12:53]

[End of Audio]