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Museum Exhibitions of Fossil Specimens Into Commercial Products: Unexpected Outflow of 3D Models due to Unwritten Image Policies

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Recent innovations and cost reductions in photogrammetry-based 3D modeling have enabled museum visitors to create 3D models based on photographs exhibited in galleries without breaking museum policies. While several museums make 3D museum data available on sharing platforms, museum visitors publish unofficial 3D data belonging to museum exhibits using a photogrammetry-based approach. This study shows that photogrammetry-based 3D models can be generated without breaking conventional photo policies (i.e., no use of flash and tripods) and that museum visitors can create commercial products based on these models. 3D models certainly enhance scientific value and promote broader and deeper interests in the natural sciences; however, the rights of owners of museum pieces are ambiguous with regard to the dissemination of unofficial data. This also makes information attributable to the original specimen unclear, which can potentially lead to revenue loss. We propose a set of best practices for museum photo policies covering the data use of visitor-generated 3D models of displayed objects.

Keywords: photography, photogrammetry, 3D model, museum exhibition, fossil-replica, photo policy, museum policy

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INTRODUCTION

Actual scale replicas of original fossils have greatly contributed to research and museum exhibitions in paleontology and other disciplines. Conventional techniques of duplication have supplemented paleontological research—especially for original fossils, which are not easily accessible or have strict regulations on use and export—as choosing appropriate molding compounds and casting materials can enhance the precision of fossil replicas.

The benefits of molding and casting are clearly visible to the public in museum exhibitions. Many of us must have seen the casts of a complete *Tyrannosaurus rex* skeleton displayed in museums. Museum visitors can appreciate the scientific background of ancient organisms through fossil replicas of original specimens otherwise stored in collection rooms. Additionally, conventional duplication techniques (i.e., molding and casting) have shown great potential for innovative exhibition styles such as hanging casts of ceratopsian dinosaurs on a wall in the Natural History Museum of Utah (**Figure 1A**), where a phylogenetic tree is painted.

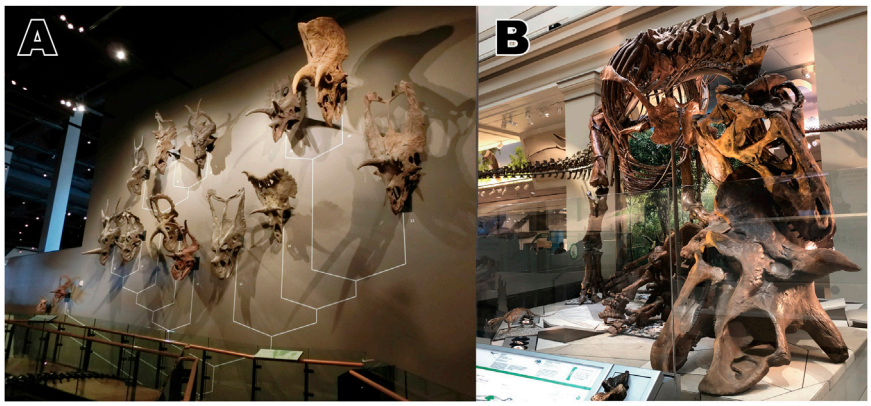

FIGURE 1 | Museum exhibitions using replica fossils. **(A)** An exhibition of the phylogenetic relationships of ceratopsian dinosaurs using skull replicas at the Natural History Museum of Utah, United States; **(B)** The nation's *T. rex* (*Tyrannosaurus rex* specimen, USNM PAL 555000) decapitating a *Triceratops horridus* (USNM PAL 500000) at the David H. Koch Hall of Fossils—Deep Time, at National Museum of Natural History, Smithsonian Institution, United States.

Until a decade ago, fossil replicas for research and exhibition were almost exclusively created using molding and casting techniques (Leiggi and May, 2005). In addition, this complex methodology has been further limited by copyright/ownership restrictions on fossil specimens with fossil replication conducted internally in the context of research, museum exhibitions, and education. However, with recent developments in technology, 3D printing and digital models have increasingly risen as a new method for creating cheap and accurate fossil replicas (Falkingham, 2012; Das et al., 2017). This noninvasive technique is preferable especially for fragile specimens because 3D-printed replicas can be made more securely with a low risk of breaking during the replication process. An example of this is the life-sized *Triceratops horridus* fossil replicas based on 3D digital models displayed in the National Museum of Natural History, Smithsonian Institution (United States) (**Figure 1B**). 3D-printed replicas are also used as educational tools (Johnson and Carter, 2019; Ziegler et al., 2020). Additionally, the Florida Museum of Natural History compiled their applications of 3D paleontological data and the related challenges for museum research and outreach (Ziegler et al., 2020).

Currently, photogrammetry-based reconstruction allows museum visitors to create digital models of museum displays and even share the models on online platforms. If the source photos are collected against museum policy (e.g., "no flash" or "no selfie stick"), creating 3D models based on these is considered a violation of museum policy. However, if model makers (i.e., museum visitors) follow the current museum photo policies while creating 3D models of museum displays, museums encounter an ambiguous situation in which the copyright of the models technically belongs to the model makers even though the museums own the specimens.

3D models are constructed through two processes: 1) capturing photos and 2) creating 3D models from the photos. In this case, photographers own the copyright of the photos used to create 3D models while the copyright of the 3D models belongs to the model creators. Here, we demonstrate that photogrammetry-based 3D models can be created without breaching photo policies, and 3D-printed objects of the models are of decent quality and may be distributed commercially. Further, in some 3D model sharing platforms, we confirmed that many photogrammetry-based 3D data of museum displays created by individuals who are not museum staff have been uploaded for sale, and companies use these data to sell 3D-printed products. These situations are often discussed on social networking sites (SNS such as Twitter or Facebook), but no actual statement or response has been issued from museums of natural sciences.

3D-Model Outflow Under Conventional Photo Policies

Currently, there is a major trend of making digital 3D models of natural history objects accessible and visible to the public. For example, the National Science Foundation-funded oVert is a research-driven project that shares digital 3D vertebrate anatomical models with the public including high-resolution anatomical data of more than 80% of vertebrate genera (Hoose, 2017). Major academic publishers such as Taylor & Francis also have official accounts with Sketchfab (Sketchfab, 2021a), a major platform for sharing, buying, and selling 3D content, as well as archiving 3D models, as in the case of Journal of Vertebrate Paleontology (Sketchfab, 2017b). Several museums, including the Natural History Museum of Los Angeles County, United States (Sketchfab, 2017a; Obied et al., 2019), and the Natural History Museum, London, United Kingdom (Sketchfab, 2016), have made their fossil collections available to users as open-access 3D models *via* Sketchfab. Many photogrammetry-based 3D models of museum displays have been uploaded by general users in addition to official 3D digital models uploaded and released by museums or academic publishers.

On Sketchfab, we identified the following user-uploaded 3D models: the *Tyrannosaurus rex* specimen ("Black Beauty," RTMP 81.6.1 at the Royal Tyrrell Museum), a nest of the duck-like

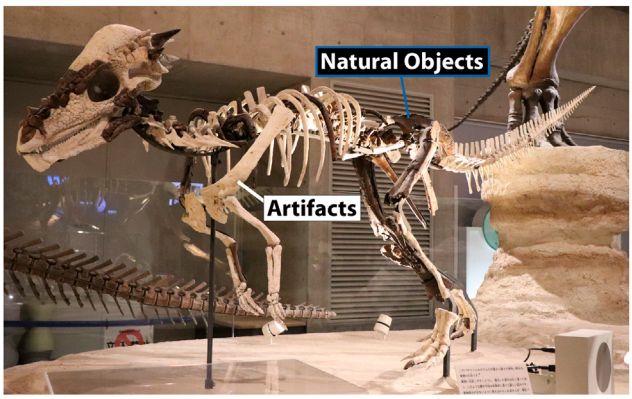

FIGURE 2 | A skeleton of *Pachycephalosaurus wyomingensis* (NMNS PV20423) in Evolution of Life, Exploring the Mysteries of Dinosaur Evolution, Global Gallery. Dark brown parts are original fossils. White parts are artifacts.

dinosaur *Maiasaura* (the Natural History Museum, London), and a specimen of the early Ceratopsian *Protoceratops* (the American Museum of Natural History). These are examples of "digitally snatched" models generated from photographs taken in the exhibition halls at the abovementioned museums. These 3D data have various Creative Commons (CC) licenses (Creative Commons, 2021) defined by uploaders, and some permit them to be used for commercial purposes. These platforms are rapidly developing in terms of both number of users and model availability. Digitized museum exhibits are freely available online, and their contents are used for various purposes. Occasionally, some models are sold under creator copyrights without an official permit from museums or specimen owners (i.e., national or local governments).

Museums own their exhibits, but natural history specimens (natural objects) that are not manmade are not copyrightable. However, we emphasize that fossil exhibits, especially vertebrate paleontology (e.g., dinosaurs or extinct mammals), are unique compared to other displays of natural objects in that many reconstructed skeletons are composed of not only natural objects or their replicas but also skeletal parts created by model-makers (**Figure 2**). For exhibitions of vertebrate paleontology, it is a common procedure for model-makers to produce "original" forms based on taphonomically deformed or incomplete fossils. Such creative assets are copyrighted. In fact, under U.S. copyright law, 17 US Code § 106 (2) guarantees "the owner of copyright to have the exclusive rights [. . .] to prepare derivative works based upon the copyrighted work," meaning, according to Menell and Vacca (2019), that "a photograph or scan of copyrighted two- or three-dimensional work implicates the derivative work or adaptation right." Thus, a scanned 3D model of a reconstructed skeleton would contain natural objects and copyrighted derivative work. Menell and Vacca (2019) further note that, "likewise, those who download and modify CAD files likely violate the adaptation right, as well as those who subsequently print the modified product."

The treatment of copyright holders of 3D files remains under active debate (Weinberg, 2013). For example, Schwartz (2015) provide the following assessment based on the U.S. laws, ". . .there may be some copyright protection in a 3D scanned image if the operator of the scanner selects the lighting components, the position of the scanners, the rate of scanning, etc. However, such copyright protection would be difficult to claim if the process is entirely automated and operator's contribution is merely to insert the object into the machine and hit the start button" (p. 5). In contrast, Menell and Vacca (2019) present the following assessment, ". . .the CAD (Computer-Aided Design) file owner might still enforce its copyright against those who reproduce and distribute the CAD file, although even that copyright could be invalid if created without authorization".

To summarize those two papers, the copyright of 3D scanned data will be approved for the creator only if he/she was authorized by the owner of the copyrighted objects.

In Japan, the Verification Investigation and Verification and Investigation Planning Committee Intellectual Property Strategy Headquarters and Next Generation IP System Review Committee (2016) published statements on the current situation of copyrights of 3D data in current Japanese copyright laws. According to their report, Japanese law does not approve copyright for 3D models if the base of the 3D model is already copyrighted (e.g., character figures) or modified by someone after scanning. In the European Commission (EU), there is a study about the intellectual property (IP) implications for industrial 3D printing and how the existing IP framework brings protection to IP rights holders (Mendis et al., 2020). This report mentions that, under the patent law, it remains unclear how claims attempting to protect the 3D data could be formulated in patent applications and whether Patent Offices could accept them as valid. Although data-sharing platforms are used worldwide, there is a possibility that museum collections may be disseminated in countries with copyrights belonging to third parties.

Discussions about the use of open 3D fossil data have only just begun. Some researchers have proposed the best practices for quality control, publication, storage, and reuse of open data using digital morphology (e.g., Davies et al., 2017), and recent movements toward sharing 3D datasets of paleontological specimens are summarized in Cunningham et al. (2014) and Davies et al. (2017). This study summarized the photo policies of major natural history museums in North America, Europe, Asia, and Oceania, which receive more than two million visitors per year. We demonstrated that commercial products can be created with photogrammetry-based 3D models of displayed fossils and suggested the best practices for museum photo policies, which cover the data use of visitor-generated 3D models of displayed objects.

MATERIALS AND METHODS

Commercial Products

To test whether we could create good-quality photogrammetry-based 3D models under current policies, we photographed two specimens displayed at the National Museum of Nature and Science in Tokyo, Japan: a fossil of *Hyaenodon* (in Evolution of life—From the Earth's Origin through Human Existence, Global

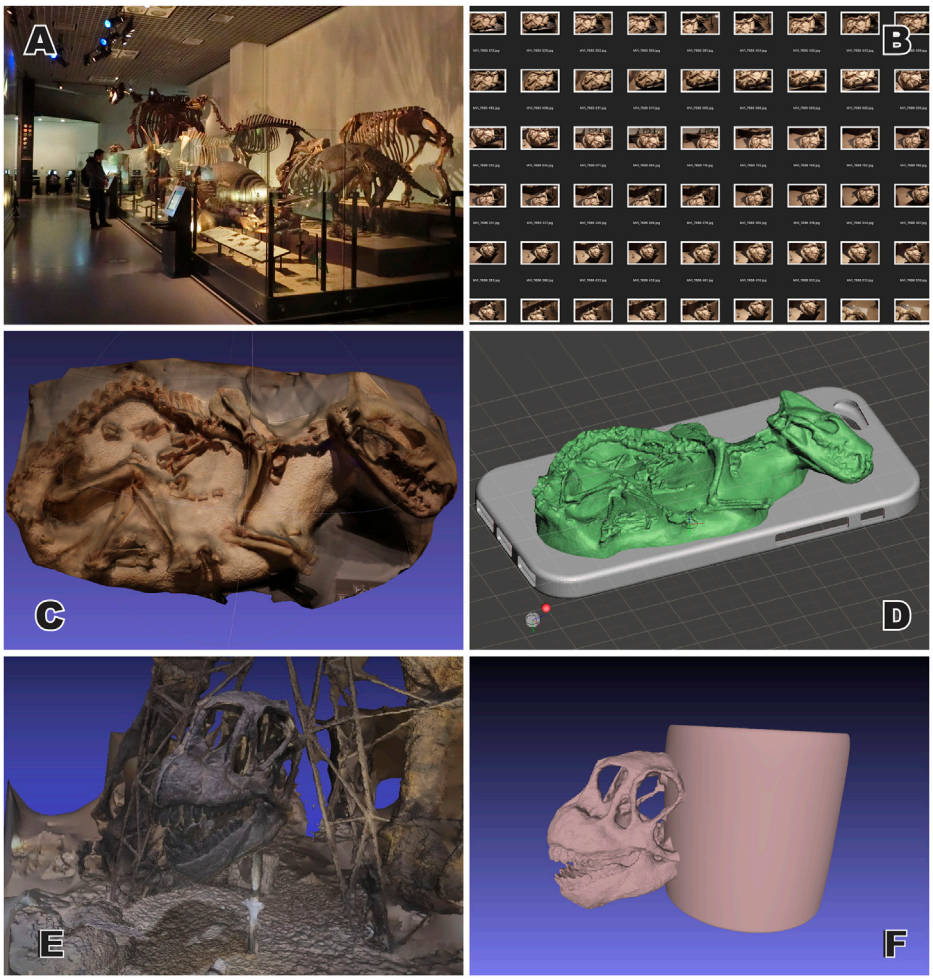

FIGURE 3 | Photogrammetry-based 3D models of the *Hyaenodon* and *Camarasaurus* skulls and their virtual products. **(A)** Exhibition gallery at the National Museum of Nature and Science, Tokyo, Japan. Fossils were displayed behind glass walls. Lighting conditions change from dawn to twilight; and, walkways were dimmed. These conditions are generally not ideal for photogrammetry (Agisoft, 2018). **(B)** Photos of *Hyaenodon* displayed in a permanent exhibition gallery. These were taken under museum photo policies and later used to create a photogrammetry-based 3D model. **(C)** Photogrammetry-based 3D model of *Hyaenodon*. It was constructed using the Agisoft Metashape (Agisoft, 2018). **(D)** Original smartphone cover as a virtual product made using the *Hyaenodon* model. **(E)** Photogrammetry-based 3D model of the *Camarasaurus* skull. It was constructed using the Agisoft Metashape (Agisoft, 2018). **(F)** Original mug as a virtual product made using the *Camarasaurus* skull model. We merged the *Camarasaurus* skull model and a 3D model of a mug in the Meshmixer (Autodesk, 2017).

Gallery) and a cast of a *Camarasaurus* skull (Evolution of Life, Exploring the Mysteries of Dinosaur Evolution, Global Gallery) following the museum's current policies (i.e., no flashlight, no additional lighting, no selfie stick, no tripod/monopod) during open hours. *Hyaenodon* is displayed behind a glass wall with lighting settings that automatically change from dawn to twilight mode (**Figure 3A**), which is not ideal for professional photogrammetry. A smartphone (iPhone 8: Apple, Inc.) and a single lens reflex (SLR) digital camera (Canon EOS Kiss X9i: Canon) were chosen as they are popular photographic equipment for photogrammetry. We took 100–200 photos of *Hyaenodon* with an SLR camera and *Camarasaurus* using a smartphone. HD movie videos were also shot. The video files were converted to still images (**Figure 3B**) using a free video-to-JPG converter (Digital Wave, 2020). To create 3D models, we used Agisoft Metashape v. 1.5 (Agisoft, 2018), which is an affordable high-end photogrammetric program for small businesses. The default settings were set for accurate photography alignment and dense clouds. We further designed a smartphone cover with the *Hyaenodon* model (**Figures 3C,D**) and a cup of *Camarasaurus* skull (**Figures 3E,F**) using the free 3D modeling software Meshmixer (Autodesk, 2017) to serve as samples of potential commercial products.

Photo Policies

To compare general photo policies in natural history museums worldwide, we compiled photo regulations as well as the number of museum visitors, which serves as an indicator of potential influence on people, from the websites of these museums, governments' reports, and the Theme Index and Museum Index (Rubin, 2020, 2021). We were able to compile data from 31 major museums, covering as many localities as possible from

TABLE 1 | Policies about photography in major natural history museums worldwide.

Museum name	Continent	Personal use	Non-commercial use	Commercial use	Secondary use	Number of visitors (2019)	References
American Museum of Natural History, United States	North America	Permitted	Application required	Restricted	Restricted	5,000,000	American Museum of Natural History (2020), Rubin (2020)
National Museum of Natural History, Smithsonian Institution, United States	North America	Permitted	Permitted	Application required	Not mentioned	4,200,000	National Museum of Natural History S.I, (2017, 2020), Rubin (2021)
Field Museum, United States	North America	Permitted	Permitted	Restricted	Not mentioned	1,494,000	Rubin, (2021), Field Museum, (2022)
Natural History Museum of Los Angeles County, United States	North America	Not mentioned	Application required	Application required	Not mentioned	1,300,000	The Natural History Museums of Los Angeles County, (2020, 2022)
Royal Tyrrell Museum, Canada	North America	Permitted	Permitted	Application required	Not mentioned	1,300,000	Royal Tyrell Museum, (2020a, 2020b)
Museo de Historia Natural, Mexico	North America	Not mentioned	Not mentioned	Not mentioned	Not mentioned	NO DATA	Secretaría del Medio Ambiente, (2022)
The Natural History Museum, United Kingdom	Europe	Permitted	Application required and/or Charge required	Application required	Not mentioned	5,424,000	The Natural History Museum (2020a, 2020b), Rubin (2020)
Muséum National D'histoire Naturelle, France	Europe	Permitted	Application required and/or Charge required	Charge required	Not mentioned	3,325,000	Muséum national d'Histoire naturelle (2020a, 2020b, 2020c)
Museum Für Naturkunde, Germany	Europe	Permitted	Permitted	Charge required	Not mentioned	737,000	The Museum für Naturkunde (2020), Museum für Naturkunde Berlin (2020)
Naturalis Biodiversity Center, Netherlands	Europe	Permitted	Permitted	Application required	Not mentioned	825,000*	Naturalis, (2021, 2022a, 2022b)
Royal Belgian Institute of Natural Sciences, Belgium	Europe	Permitted	Application required	Application required	Application required	353,000	Royal Belgian Institute of Natural Sciences, (2022a, 2022b)
National Museum of Nature and Science, Japan	Asia	Permitted	Application required	Charge required	Application required	2,460,000	National Museum of Nature and Science (2020a, 2020b), Rubin (2021)
Shanghai Science and Technology Museum, China	Asia	Permitted (no selfie sticks and tripods)	Not mentioned	Not mentioned	Not mentioned	4,824,000	Shanghai Natural History Museum, (2014), Rubin, (2021)
China Science and Technology Museum, China	Asia	Not mentioned	Not mentioned	Not mentioned	Not mentioned	3,891,000	China Science and Technology Museum in Beijing, (2021), Rubin, 2021)
National Taiwan Museum, Taiwan	Asia	No flash and camera supports	Prohibit	Prohibit	Prohibit	3,000,000	National Taiwan Museum, (2022) Rubin, (2021)
Indian Museum, Kolkata, India	Asia	Charge required	Not mentioned	Not mentioned	Not mentioned	NO DATA	Indian Museum (2022)
Lee Kong Chian Natural History Museum, National University of Singapore, Singapore	Asia	No flash and selfie sticks	Not mentioned	Not mentioned	Not mentioned	NO DATA	Lee Kong Chian Natural History Museum (2022)
Bahrain National Museum, Bahrain	Asia	Permitted	Special requests required	Special requests required	Special requests required	123,000*	The Bahrain Authority for Culture and Antiquities (2019), The Bahrain Authority for Culture and Antiquities, (2022)

(Continued on following page)

TABLE 1 | (*Continued*) Policies about photography in major natural history museums worldwide.

Museum name	Continent	Personal use	Non-commercial use	Commercial use	Secondary use	Number of visitors (2019)	References
Museum of New Zealand Te Papa Tongarewa, New Zealand	Oceania	Permitted	Permitted	Application required	Not mentioned	1,548,000	Museum of New Zealand Te Papa Tongarewa, (2019), Museum of New Zealand Te Papa Tongarewa, (2021a), Museum of New Zealand Te Papa Tongarewa, (2021b)
The Australian Museum, New South Wales, Australia	Oceania	Permitted (except for some galleries)	Charge required (exemptions may apply.)	Special requests required	Not mentioned	446,931	The Australian Museum, (2019), The Australian Museum, (2022)
Museums Victoria, Australia	Oceania	Permitted (no flash)	Not mentioned	Not mentioned	Not mentioned	1,972,786	Museums Victoria, (2020, 2022)
Museo Argentino de Ciencias Naturales Bernardino Rivadavia, Argentina	South America	Application required	No permission required	Special requests required	Special requests required	NO DATA	Museo Argentino de Ciencias Naturales "Bernardino Rivadavia" (2013)
Museo Nacional de Historia Natural Chile, Chile	South America	Not mentioned	Not mentioned	Not mentioned	Not mentioned	NO DATA	Museo Nacional de Historia Natural Chile (2022)
Museo de Historia Natural, Universidad Nacional Mayor de San Marcos, Peru	South America	Not mentioned	Not mentioned	Not mentioned	Not mentioned	NO DATA	Museo de Historia Natural (2017)
Museo de Historia Natural de la Universidad del Cauca, Colombia	South America	Permitted (no flash and tripod)	Application required	Application required	Application required	NO DATA	Museo de Historia Natural de la Universidad del Cauca (2022)
National Museum, Rio de Janeiro, Brasil	South America	NO WEB PAGES	NO WEB PAGES	NO WEB PAGES	NO WEB PAGES	CLOSED	NO ACTIVE WEB PAGES
The Ditsong: National Museum of Natural History, South Africa	Africa	Flash photography is prohibited	Application required	Application required	Application required	280,000	Laws.Africa Legislation Commons (2016), Ditsong Museums of South Africa (2020)
The National Museum, Bloemfontein, South Africa	Africa	Flash photography is prohibited	Application required	Application required	Application required	220,000	Laws.Africa Legislation Commons (2016), Jen Snowball et al. (2019)
The National Museums of Kenya, Kenya	Africa	Not mentioned	Send requests to the office	Send requests to the office	Send requests to the office	1,000,000	National Museums of Kenya (2020)
Natural History Museum of Zimbabwe, Zimbabwe	Africa	Not mentioned	Not mentioned	Not mentioned	Not mentioned	NO DATA	Natural History Museum of Zimbabwe (2022)
Uganda Museum, Uganda	Africa	Charge required	Charge required	Not mentioned	Not mentioned	Not available	Sebuliba (2020), The Uganda Museums (2022)

every continent (North America, Europe, Asia, Oceania, Africa, and South America), which receive more than 43 million visitors per year.

They were listed as follow (**Table 1**): six museums from North America (American Museum of Natural History, United States; National Museum of Natural History, Smithsonian Institution, United States; Field Museum, United States; Natural History Museum of Los Angeles County, United States; Royal Tyrrell Museum, Canada; Museo de Historia Natural, Mexico), five museums from Europe (The Natural History Museum, United Kingdom; Muséum National D'histoire Naturelle, France; Museum Für Naturkunde, Germany; Naturalis Biodiversity Center, Netherlands; Royal Belgian Institute of Natural Sciences, Belgium), seven museums from Asia (National Museum of Nature and Science, Japan; Shanghai Science and Technology Museum, China; China Science and Technology Museum, China; National Taiwan Museum, Taiwan; Indian Museum, Kolkata, India; Lee Kong Chian Natural History Museum, National University of Singapore, Singapore; Bahrain National Museum, Bahrain), three museums from Oceania (Museum of New Zealand Te Papa Tongarewa, New Zealand; The Australian Museum, New South Wales, Australia; Museums Victoria, Australia), five museums from South America (Museo Argentino de Ciencias

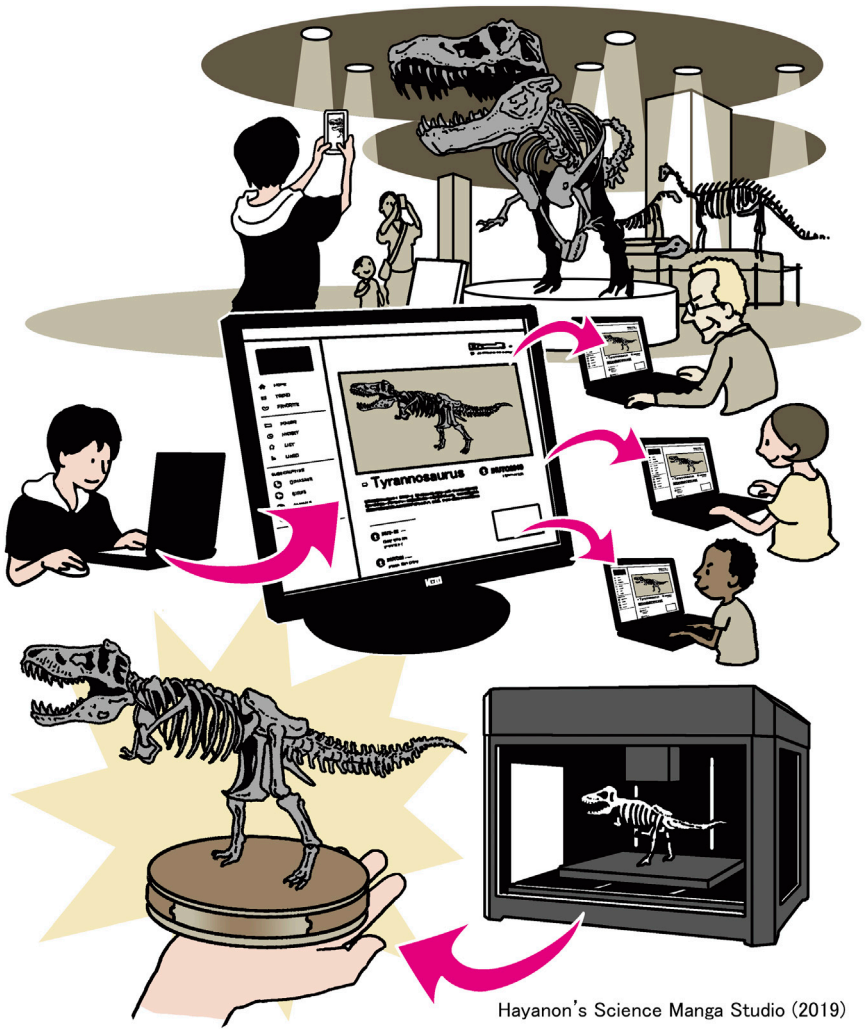

FIGURE 4 | From photographs of a museum exhibit to a 3D-printed product in hand. Innovation and cost reduction in photogrammetry can assist museum visitors in making 3D digital models based on photographs taken in the exhibition hall without breaking museum policies and allow them to publish these to sharing platforms. Illustrated by Hayanon, Hayanon's Science Manga Studio (https://www.hayanon.jp/).

Naturales Bernardino Rivadavia, Argentina; Museo Nacional de Historia Natural Chile, Chile; Museo de Historia Natural, Universidad Nacional Mayor de San Marcos, Peru; Museo de Historia Natural de la Universidad del Cauca, Colombia; National Museum, Rio de Janeiro, Brazil), and five museums from Africa (The Ditsong National Museum of Natural History, South Africa; The National Museum, Bloemfontein, South Africa; The National Museums of Kenya, 2019 Kenya; Natural History Museum of Zimbabwe, Zimbabwe; Uganda Museum, Uganda).

"DIGITAL SNATCH" DISPLAYED OBJECTS

The photo policy of the National Museum of Nature and Science, Tokyo, Japan, is displayed at every building entrance, in booklets, and on its website (National Museum of Nature and Science, 2020a). We were able to obtain photos without violating any of the museum's photo policies, and these were used to generate 3D models of decent quality and a virtual commercial product from the photogrammetry-based 3D model (**Figures 3C–F**). We spent only a few minutes photographing the objects and used all the photo and video data to create the models. Based on photos and videos taken through a glass wall, we obtained 3D models of objects displayed below eye level at sufficiently good quality for printing, selling, or sharing (**Figures 3C**, **4**). On the other hand, complete 3D models of large specimens or those displayed in high places could not be acquired as the dorsal/backside of the specimens were not accessible to visitors.

The *Hyaenodon* and *Camarasaurus* skull specimens were not displayed under suitable photographic conditions for photogrammetry (**Figure 3A**). The exhibition hall had variable light conditions ranging from dark (dawn) to bright (daytime)

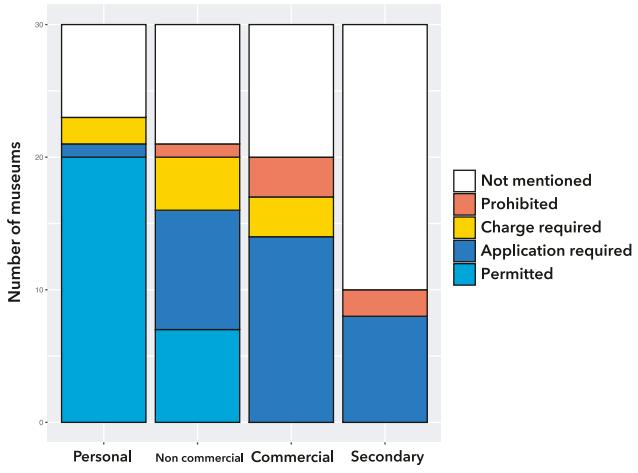

FIGURE 5 | Stacked bar charts of the generalized trend of museum policies. The data were collected from **Table 1**. Legends are shown in the right side of the figure. These charts were created in R (R Core Team, 2021).

modes. Even so, the software algorithms were able to align photos to generate 3D digital models that retain the extreme morphological details of the surface.

Once 3D models are uploaded to online data-sharing platforms like Sketchfab (Sketchfab, 2012) or Pinshape (Pinshape, 2016), they can be distributed rapidly. A third party can download them to make commercial products for profit (**Figure 4**). This "digital snatch" of a museum exhibition, which may be unwanted dissemination of digital files or copyright infringement of 3D properties, is easier than ever because of widespread advancements in photogrammetry techniques. Currently, the market price of photogrammetry software ranges from hundreds to thousands of dollars (e.g., Reality Capture (Capturing Reality, 2016), Agisoft Metashape (Agisoft, 2018), 3DF Zephyr (3D Flow, 2014),and ReCap (Autodesk, 2020)). There are also free, open-source photogrammetry programs such as 3DF Zephyr Free (3D Flow) and smartphone applications (e.g., Qlone: EyeCue Vision Technologiesm, 2017).

Because earned income accounts for various percentages of museum revenue, a "digital snatch" will reduce museums' potential profit (sales of replicas of exhibited specimens, etc.), which might be a critical issue for privately owned or small museums. Although many natural history museums are managed as public properties, not all museums are managed fully by government funding, as with the National Museum of Nature and Science, Tokyo, Japan.

MAJOR NATURAL MUSEUMS' PHOTO POLICIES

The photo policies of eight major natural history museums worldwide (North America, Europe, Asia, Oceania, Africa, and South America) are listed in **Table 1** and **Figures 5**, **6**. We compared 31 museums' photographing regulations for private, noncommercial, and secondary use. Among the museums we selected, one (National Museum, Rio de Janeiro, Brazil) has no active website, and five do not mention their photographing policies on their websites. Although some museums have restrictions on usage of flash and tripods, 20 permit visitors to

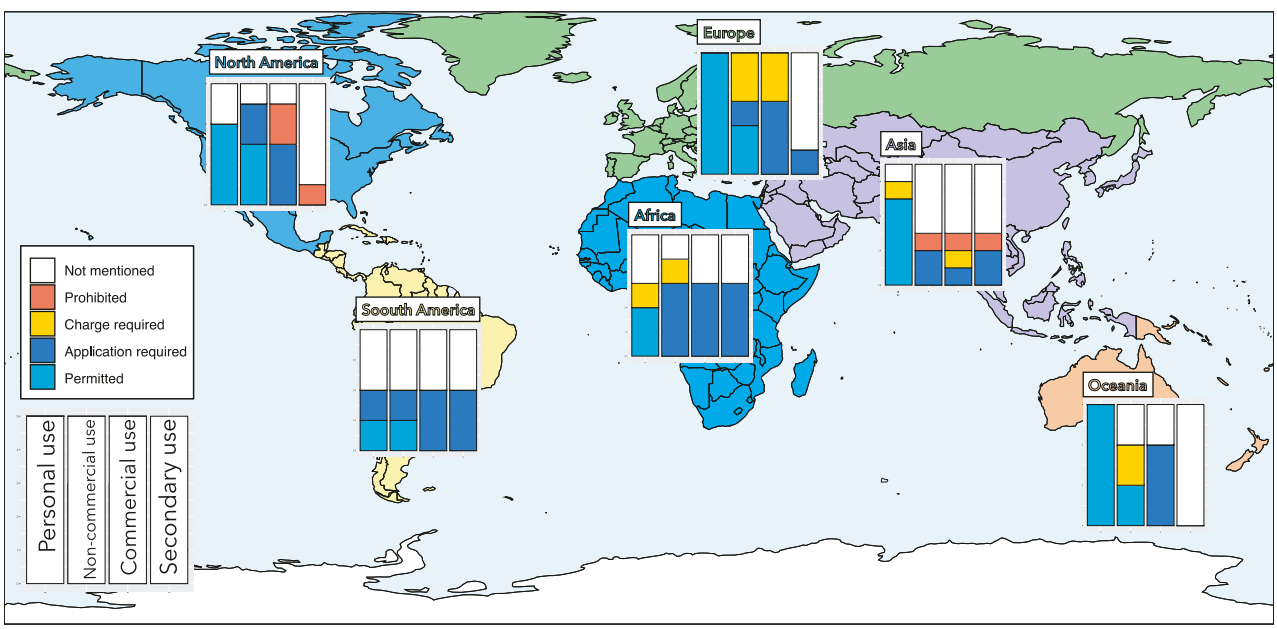

FIGURE 6 | Stacked bar charts of global trends of museum policies. The data were collected from **Table 1**. Legends are shown on the left side of the figure. These charts were created in R (R Core Team, 2021).

take photos in their exhibitions. Two museums charge fees for photographing inside their galleries, and one requires an application for museum visitors (**Figure 5**). Seven museums allow visitors to use photos they take for noncommercial purposes while 13 require them to send applications (along with monetary fees in some cases). In addition, one museum prohibits visitors from using photos for noncommercial profits. No museum allows visitors to use of their exhibitions' photos for commercial purposes without applications, and three museums prohibit it entirely. Among the museums listed in **Table 1**, only one-third mention policies for secondary use. These say that museum visitors and the people who download photos collected by museum visitors must use them personally or, even in the most permissive cases, only for noncommercial purposes (**Figure 5**; **Table 1**).

We also compared photo policy trends by continent. In South America, the number of museums that mention photo policies on their websites is small compared to other continents. Europe, North America, and Oceania have similar trends of museum photo policies. In those three areas, all museums allow visitors to take photos freely in their museums, and some of the museums allow exhibition photos for noncommercial purposes. In those three areas, photo policies regarding personal, noncommercial, and commercial use are clearly presented on their websites, but most museums do not mention secondary use on their website. On the other hand, Africa and Asia include museums that charge fees for taking photos in the museums. In addition, no museums allow visitors to use their photos for noncommercial purposes. In Asia, many museums do not mention noncommercial, commercial, and secondary use on their websites.

We emphasize that there should be no conflict between public property and limiting data leakage. For example, the 3D model of the most famous dinosaur, *Tyrannosaurus rex,* known as "SUE" (PR 2081), is officially available for education and creative work on the official Sketchfab account of the Field Museum (Sketchfab, 2018), but the data are not downloadable. This is an excellent example of releasing 3D data while retaining the copyright. Regardless of whether user-generated 3D data of displayed objects are appropriate, if museums prefer to control the secondary use of these data, conventional photo policies (e.g., no flash, no selfie sticks or tripods) are insufficient.

CREATIVE COMMONS 0 IN NATURAL SCIENCES

The Smithsonian Institution (including 19 museums, 12 libraries, nine research institutes, and one zoo) announced the launch of Smithsonian Open Access in which 2.8 million of their digital collection images were released into the public domain (Smithonian Institution, 2020). Digital images including 2D and 3D data of the Smithsonian collections published by the Smithsonian Institution (Smithonian Institution, 2020) can be used without permission and payment for any purpose (Fisher and Thomas, 2020) under the CC0 policy. CC licenses are standardized "communication tools" for creators to grant various degrees of permission to share and use their creative work. CC licenses are standardized ways of granting public permission to use their work under copyright laws. CC licenses are also legal tools through which creators and other rights holders can offer certain usage rights to the public while other rights are retained because these licenses were originally created based on copyright laws (Creative Commons, 2022a, 2022b; Creative Commons Japan, 2022). There are six different license types: CCBY, CC BY-SA, CC BY-NC, CC BY-NC-SA, CC BY-ND, and CC BY-NC-ND. CC, as previously defined, refers to Creative Commons. BY means that the creator must give original credit, SA means that users must share adaptations under the same terms, NC indicates that only noncommercial uses of the work are permitted, and ND means that no derivatives or adaptations of the work are permitted. Additionally, CC licenses have a subcategory: CC0. CC0 means "no rights reserved"; it waives all rights of creators and places their work in the public domain as much as possible. Users can reuse these works for any purposes without restriction under copyright or database law (Creative Commons, 2020). In the case of the Smithsonian, this effort has the imprimatur of its administration. Regarding the Smithsonian Open Access, Smithsonian Secretary Lonnie G. Bunch III stated that the institutional effort aimed for "viewers to become collaborators to engage critically, to think expansively, to imagine freely" (Bunch, 2020). Before the CC0 policy, the Smithsonian Institution allowed users to download their copyrighted data and use them for purposes under fair use. Fair use ("fair dealing" in the United Kingdom) is a legal doctrine that promotes freedom of expression by permitting the unlicensed use of copyright-protected works in certain circumstances (e.g., nonprofit educational and noncommercial uses), and many countries use this policy (e.g., the Copyright Act 1911 in the United Kingdom or 17 U.S. Code § 107 in the US). The new CC0 policy opens the doors of the Smithsonian Institution to people in countries that do not allow fair use, such as Japan, where both authors are based. By becoming the first natural history museum to enact the CC0 policy for 3D datasets, they showed that museum collections belong to the public common and removed economic and legal barriers to promote equity by permitting anyone in the world to make creations based on their exhibited collections.

The Natural History Museum in London and the Field Museum also released 2D images with limited data under the CC0 policy, but these do not include 3D models (The Natural History Museum, 2017; Field Museum, 2021). The former museum has released many downloadable 3D models of important specimens (e.g., Darwin's fossil collection: The Natural History Museum, 2017) under the CC BY-NC 4.0 license but not the CC0 license. Similar efforts have been undertaken by other small museums (e.g., Western Science Center: Sketchfab, 2021b; Charleston Museum: Sketchfab, 2020; College of Charleston: Sketchfab, 2019).

DESIRABLE PHOTO POLICIES TUNED FOR 3D DATA

Open-access sharing platforms for 2D and 3D images are increasingly popular, and some explicitly state their copyright policies and other terms of use for both data authors and users. In some cases, uploaders (e.g., data contributors as well as data authors in most cases) can determine the copyright holder by selecting copyright options during the uploading process, which may become an issue.

In paleontological research, 3D digitization and imaging techniques have already been used as research tools (e.g., Rowe and Frank, 2011; Lewis, 2019; Karasawa and Matsui, 2020; Matsui and Karasawa, 2020); however, it is only recently that research-driven archives such as MorphoMuseuM (Lebrun and Orliac, 2016) and MorphoSource (Boyer et al., 2016) have become accessible to a more general audience who are curious to see 3D models of organisms. In MorphoSource, if the restriction option is set by data contributors (i.e., uploaders, data authors), data users are required to state the purpose of using the 3D data before they are permitted to download data or send a request for download directly to the uploader. All data contributors are required to obtain official permission from specimen owners before uploading (see Davies et al., 2017).

Nowadays, 3D digital models can be shared worldwide through major sharing websites like Sketchfab (Sketchfab, 2012). Data contributors can set a CC license for each 3D object in Sketchfab, but they are not required to obtain specimen owners' permissions. In this case, 3D data can easily lose important metadata attributes associated with the data and specimen, like the location of the original specimen and specimen numbers.

Our results show that visitors can generate photogrammetry-based 3D models of displayed objects and share these models without the authorization of museums under general photo policies. If museums desire to restrict unwanted duplicates of museum objects while allowing photo shooting in their exhibition galleries, we suggest creating or revising the handling policies for 3D models of displayed objects and explicitly stating these to visitors.

BEST PRACTICES FOR DIGITAL ASSETS OF DISPLAYED 3D OBJECTS IN NATURAL HISTORY MUSEUMS

Here, we propose the best practices for museum photo policies that cover the data use of visitor-created 3D models of displayed objects.

1) Creating models: State whether museums allow visitors to take photographs to convert them into 3D models. It is important for each museum to make decisions regarding the management of the 3D data of its exhibitions.
2) Copyright of 3D models: Clarify the ownership of any type of 3D model of displayed objects as part of photo policies. During the COVID-19 pandemic (2020–ongoing), virtual reality or augmented reality exhibition could be considered as a new source of museum income. A statement about ownership is especially important when museums plan to sell 3D-printed replicas or other products.
3) Commercial versus noncommercial use: Clearly state whether visitors can publish their models for commercial or noncommercial use. For example, many museums display replica of fossil specimens owned by other museums. The copyright of the original specimens must be clarified before publication. Considering these circumstances, we recommend specifying whether a piece in an exhibit is CC BY-NC-ND. In some cases, museums that release 3D models on websites (e.g., the Natural History Museum in London and Charleston Museum, South Carolina in United States) retain the rights for noncommercial use of their digital data in sharing platforms whereas the Smithsonian allows for the use of their published 3D models in CC0.
4) Sharing models: Clarify whether museums allow visitors to share photogrammetry-based 3D models created by museum visitors with anonymous people on the internet. If allowed, we recommend that museums request that model creators place the following in their 3D data files: scientific information about the objects (e.g., scientific name, locality, housed institution, specimen number), data acquired to date, data-acquisition equipment, and software. The attribute information is easily lost during any allocation process of the 3D models when copying and pasting files. However, these metadata attributes are the most valuable information for museum specimens. If the 3D data retain their associated information, the data could be used for future educational and research purposes.
5) Clear notification: The above policies must be stated in plain language and easily spotted by visitors in museum halls. It would be better to announce these repeatedly in multiple ways, such as through interactive kiosks, during the ticket-purchasing/reservation process, or on the museum's website. We believe it is important to retain substantial museum–visitor relationships.
6) Takedown notice: If necessary, mention that museums may request a takedown from the sharing platform when they find models that violate museum policies. Such action would heavily influence the willingness of rights holders to attempt to exercise questionable control (Schwartz, 2015). Nevertheless, to avoid a daunting process of identifying end-users for takedown action, we suggest that the museums understand IP issues regarding 3D scanning and printing of displayed objects and redesign their photo policies to fit their digital strategies.

CONCLUSIONS

This study proposes handling policies for user-generated 3D models of displayed objects. Open access policies for the reproduction of museum specimens are becoming a global trend, being promoted and implemented at varying rates and in different ways in countries worldwide. While some institutions have adopted fully open-access policies for their 2D and 3D digital data, some museums maintain stricter copyrights. This issue has not been fully discussed in many contexts, including that of small museums. Cost reduction in 3D-scanning equipment and photogrammetry software will facilitate the creation of 3D models of objects

displayed in exhibition halls. These "unofficial" models have already been uploaded to popular data-sharing platforms such as Sketchfab. Once 3D digital models of displayed objects are created by a third party, rapid online distribution cannot be controlled by museums that own original models.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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