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SUSTAINABILITY OF 3D HERITAGE DATA: LIFE CYCLE AND IMPACT

1. Introduction

Although sustainable 3D digital data management and sharing was recognized as an issue since the early stage of Digital Archaeology, it is now becoming increasingly consistent and broadly recognized (Koller *et al.* 2009; Thwaites 2013; Scopigno *et al.* 2017; Champion, Rahaman 2019; Garstki 2020). The exploit of 3D data creation in the last years has raised multiple questions on how to address delicate issues such as how to assess the impact of digital visualisations, shared metadata standards, data accessibility, maintenance, and obsolescence. On one side the large diffusion in the Cultural Heritage (CH) sector of tools, both hardware and software, for creating 3D content and sharing it on the web has been fostering a worldwide process of digitisation. On the other, the increased usage of such tools and techniques has raised multiple issues. Specifically, web browsing reveals an over-production, often reduplication, of unexploited digital data, in contrast to, ironically, a complete lack of key heritage datasets.

Such a phenomenon is particularly evident in the controversial and iconic case of the Nefertiti bust 3D model. The 3D model has been at the centre of an intense debate about open access and the rightful claim of imposing a copyright license on a copy of a heritage artefact which is already in the public domain. The debate was started by the legal dispute between Cosmo Wenman, a digital artist who asked the Neues Museum of Berlin for the 3D scan data of the bust, and the Prussian Cultural Heritage Foundation[1] (Pittman 2020). Currently, this represents possibly one of the most (over) shared digital heritage models and on Sketchfab alone already has more than fifteen identical versions uploaded by different authors[2].

If this example undoubtedly represents a major victory for the open access community, it also delineates a dualism: over-sharing as opposed to the lack of proper organised 3D documentation of most of the European archaeological sites, historical buildings, monuments, and museums' collections made accessible for research purposes.

[1] For further reading on the legal dispute please visit: https://reason.com/2019/11/13/a-german-museum-tried-to-hide-this-stunning-3d-scan-of-an-iconic-egyptian-artifact-today-you-can-see-it-for-the-first-time/, accessed on 20/06/2022. For the correspondence between the two parts: https://cosmowenman.files.wordpress.com/2019/10/20191029-cosmo-wenman-nefertiti-3d-scan-foia-effort.pdf, accessed on 20/06/2022.

[2] https://sketchfab.com/search?category=cultural-heritage-history&features=downloadable&q=nefertiti&type=models, accessed on 10/06/2022)

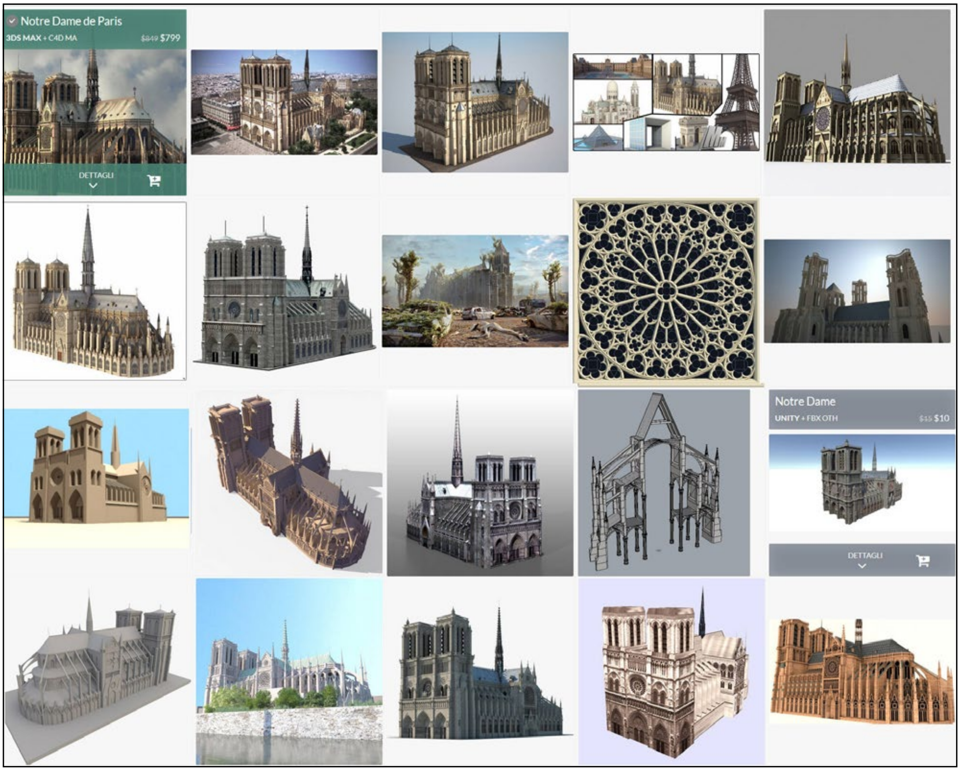

Fig. 1 – Image gallery of Notre Dame 3D models available online.

A dramatic example of the latter comes from recent history, and it is the Notre Dame cathedral in Paris. The whole structure apparently was 3D recorded after several laser scanning campaigns in 2011 and 2012 by an American Art professor from Vassar University, Andrew Tallon (Sandron, Tallon 2013; Tallon 2014). A series of dramatic events, such as the death of Dr Tallon in 2018 and the disaster that damaged the cathedral in 2019, combined with the fact that the 3D scans were «small enough to fit on a single hard drive, but unlikely to be stored in the cloud»[3] raised tangible concerns on how to retrieve the data from Tallon's hard disk and who should be the rightful owner of the 3D scans.

Luckily, in this case, Vassar University offered the data to help in the process of reconstruction and the ownership issues were temporarily solved.

[3] https://www.theatlantic.com/technology/archive/2019/04/laser-scans-could-help-rebuild-notre-dame-cathedral/587230/, accessed on 27/06/2022.

Currently, from a survey online it is possible to visualise some very low poly models of the cathedral made from photogrammetric elaborations of poor-quality footages. Alternatively, it is possible to buy a digitally made copy of the cathedral with a price range that goes from 8 dollars up to 800 (Fig. 1). There is no web trace of Tallon's raw 3D scans[4], and the risk of data loss remains still unsolved.

Are we, as researchers, really exploiting the possibilities offered by 3D data produced by other institutions or colleagues? Could we afford to adopt a 'digitise everything approach' without a proper strategy that involves how reducing environmental harm?

2. State of art and research questions

As recognised by Champion, Rahaman (2019), even though the European Union funded massive projects focused on infrastructure development (among them: Europeana, Ariadne, Ariadne Plus, Carare, 3D-ICONS; D'Andrea *et al.* 2012; Di Giulio *et al.* 2021), the possibilities offered by 3D data as scholarly resources are far from being fully exploited (Muenster 2022). The issue of a missing scholarly digital eco-system has been raised extensively and multiple times by, among others, Champion (Champion, Rahaman 2019, 2020). The web is nowadays the main channel for the dissemination of knowledge and emerging commercial solutions for web-publishing of 3D data are consolidating and becoming a de-facto standard for many applications. If indeed, there is an increasing diffusion of 3D recorded CH artefacts, sites and buildings, there is still very poor exploitation in terms of raw data web publication capabilities. As noted by R. Scopigno, there are numerous reasons possibly behind the lack of digital data sharing (Kuroczynski 2017; Scopigno *et al.* 2017) encompassing both geometry and color. What remains still an open problem is how to deliver those data and related knowledge to our society. The lack of data sharing can be attributed to several widely prevalent causes, including:

– Intellectual property rights issues.
– Fear of misuse (i.e., commercial use without authorisation) or use without proper citation.
– Fear of disclosing data part of ongoing or unpublished research.
– Lack of expertise or adequate financial support.

Even though in recent years a huge effort has been invested in creating a shared set of paradata and metadata standards (Batini *et al.* 2009;

[4] https://shop.leica-geosystems.com/leica-blk/blog/precision-laser-scans-notre-dame-cathedral-can-help-preserve-restore-and-rebuild, accessed on 27/06/2022, the link to the scans' preview is unavailable).

Bentkowska-Kafel, Denard, Baker 2012; Hermon, Niccolucci, Ronzino 2012; Wilkinson *et al.* 2016; Aloia *et al.* 2017; Meghini *et al.* 2017; Gattiglia 2018; Richards 2021; Börjesson *et al.* 2022), there are growing concerns about how 3D data shared solely through web visualisation tools could contribute to a broader scientific debate. On the topic, Ekengren *et al.* (2021, 338) recently observed that: «Despite the multiple solutions offered by 3D visualisation technology and the different experiments carried out so far, it is still difficult to define the role and potential that 3D archives of archaeological artifacts have in producing new knowledge. So we may ask ourselves – are these 3D archives impacting higher education and research in a significant way, and what strategies and tools should we implement for transforming these instruments into assets capable of supporting multimodal engagement?».

Furthermore, there are other underestimated factors linked with digital heritage data sharing:

1) Archaeology as a discipline is mostly based on destructive research methods: the impossibility of accessing raw data of the 3D recordings of, for instance, an excavation not only inhibits scholars but also represents a tragic loss of irretrievable information. Replicability gives consistency to and is the base of a scientific approach. Although "Replicability" and "Archaeological research" look far from being linked, admittedly new advances in the Digital Archaeology methodology are going towards that direction (Frischer 2008; Demetrescu, Ferdani 2021; Dell'Unto, Landeschi 2022).

2) Data transparency against "digital faith". Compelling and aesthetically appealing digital visualisations could be deeply problematic or even misleading. A 3D model can have greater reach and impact than an academic paper but without appropriate supporting matter, transparent analysis, and citation of sources (Kuroczyński, Hauck, Dworak 2014), it offers nothing to advance rigorous scholarly debate (Frischer *et al.* 2002; Hermon, Niccolucci, D'Andrea 2005). These issues were raised alongside the well-known instances stated in the London and Seville Charters (Beacham, Denard, Niccolucci 2006; Bendicho, Lopez-Menchero 2013). In my opinion, this also applies to a certain extent to 3D models derived from a direct recording, especially when it comes to artefacts with some peculiarities or very small details that must be recorded. Accessing a final elaboration, without comparing it with raw data and paradata, could be as much misleading as a made-up reconstruction.

3) Digital data obsolescence. The UNESCO charter on the preservation of Digital Heritage in the section dedicated to "Guarding against loss of Heritage" recognizes hardware and software obsolescence as a major threat to digital data survival (Ioannides *et al.* 2012). A concern shared by, among others, Harold Thwaites (2013, 340), who stated: «we cannot afford to have

our digital heritage disappearing faster than the real heritage or the sites it seeks to 'preserve' otherwise all of our technological advances, creative interpretations, visualisations, and efforts will have been in vain». As Bernard Frischer (2005, 7) already noted, by neglecting to take measures against this risk we could very soon face a major problem called 'the death of the digit'.

4) Web platform ownership. Hosting 'sensible data' on a platform managed by a private company, that as such could, for instance, go bankrupt or decide to interrupt updates, is a major threat to data preservation.

5) Restrictions imposed by web visualisations. For most of the commercial and non-commercial platforms available online, web visualisations imply limits of file size uploads (Champion, Rahaman 2020; Fund, Schoueri, Scheibler 2021; *European Commission. Directorate General for Communications Networks, Content and Technology* 2022), therefore what is really accessible and can be visualised is a low-poly version of the original 3D model[5].

The theme of web visualisation limits must not be underestimated. Based on the ability of the 3D data producer, low-poly models could preserve a good level of texture detail through a process called 'baking'. Such a process could also be applied for normal and displacement maps to retrieve further information on some features of the scanned object, while the detail of the physical geometry of the 3D model is drastically reduced. The open question, again, is the same: is this enough to allow an independent researcher to grasp the complexity of, for instance, an artefact, a historical building, an archaeological site or even a single stratigraphic unit? Furthermore, in this scenario how quality standards could effectively counterbalance the file-sized related data loss?

When it comes to 3D data, defining quality standards is a very complicated challenge (*European Commission. Directorate General for Communications Networks, Content and Technology*, 2022), which involves the metadata schemas, architecture and standards as much as the tools used for recording a specific CH object typology (an archaeological site, a find and a monument, even though recorded through the same techniques or tools, require different approaches) up to the digital characteristics of the elaborated model (i.e., texture and mesh geometry).

An explicatory example of the impact of an unbalanced relationship between texture quality intended for web visualisation and physical geometry of the digital copy is the 3D model of the Rosetta Stone (Fig. 2), published in 2016 on Sketchfab by the British Museum[6]. The model in the texture visualisation mode appears rich in details, even though the texture quality

[5] An interesting exception is the 3DHOP tool. However, as a web visualiser it needs to be hosted on a proprietary server in order to work properly.

[6] https://sketchfab.com/3d-models/the-rosetta-stone-1e03509704a3490e99a173e53b93e282, accessed on 21/06/2022.

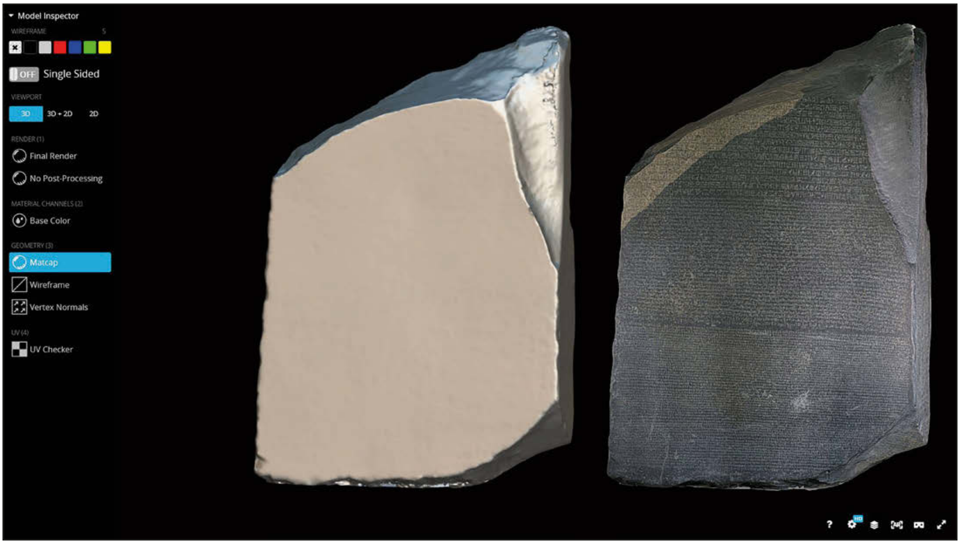

Fig. 2 – The Rosetta Stone 3D model from The British Museum Sketchfab page (left: 'matcap' visualisation mode, right: textured).

is reduced because of the web platform limits. Conversely, if we switch to 'matcap' visualisation in the model inspector panel, it shows a completely flat-surfaced geometry which did not record any of the 'physical' features of the signs left by the incisions on the stone. Therefore, the geometry definition level, under the texture, is mostly inadequate for research purposes.

The issue of inadequate research impacts is even more evident in the case of 3D recordings of large archaeological sites or historical buildings. Such 3D recording processes need substantial financial support, often granted from government funding or as part of a wider EU-funded project, to allow a team of trained specialists fully equipped to perform multiple campaigns of laser scanning acquisitions, alongside aerial and terrestrial photogrammetry. What happens afterwards with the colossal amount of raw data produced? How often do very large 3D scanning fieldwork campaigns, after having produced terabytes of point clouds, reach their peak remaining locked into local or private hard disks? The lack of proper data sharing inevitably leads to the fact that if another group of researchers wants to study the same area/monument, they will most likely need to go through two separate 3D scanning processes, doubling costs, time and resources for the same action. Not to mention that for a single scholar such a set of tasks could be far beyond the Herculean effort. We cannot afford the risk of considering these two processes, data over-reduplication and data hoarding, as two separate phenomena.

In the same way, such scenario raises an ethical dilemma: is it right that projects funded through community contributions do not share raw data with other specialists that could produce further knowledge or positive impacts on community-recognized heritage? How could this current data life cycle enhance research and cultural democracy? According to E. Kansa (2012, 507), «the discipline should not continue to tolerate the personal, self-aggrandising appropriation of CH that comes with data hoarding'; indeed, data withholding represents a clear threat to preserving the archaeological record» and could also lead to the dangerous '*campanilismo* effect' described by B. Frischer (2005, 4).

The pattern highlighted so far already shows signs of long-term unsustainability, even without considering the impact of digital data on the environment in terms of energy consumption. As already reported by Jones and Champion (Jones 2018; Champion, Rahaman 2019), even though currently the consumption of data centres is just 1% of the global electricity demand, the fast growth of this sector makes the future difficult to foresee: «Already, data centres use an estimated 200-terawatt hour (TWh) each year. That is more than the national energy consumption of some countries, including Iran, but half of the electricity used for transport worldwide, and just 1% of global electricity demand. Data centres contribute around 0.3% to overall carbon emissions, whereas the information and communications technology (ICT) ecosystem as a whole – under a sweeping definition that encompasses personal digital devices, mobile-phone networks and televisions – accounts for more than 2% of global emissions. That puts ICT's carbon footprint on a par with the aviation industry's emissions from fuel. What could happen in the future is hard to forecast. But one of the most worrying models predicts that electricity use by ICT could exceed 20% of the global total» (Jones 2018, 163).

We are past beyond the zettabyte (10^{21} bytes) era (IEA 2017), experiencing an explosion in terms of data production and Internet connections, under the risk of heavily impacting natural resources and the environment (Jones 2018; Champion, Rahaman 2019; Potts 2021). Even though one of the side effects of the pandemic crisis was a general reduction of energy consumption (IEA 2021), global electricity demand exponentially grew by 6% in 2021. It represented the largest-ever annual increase in absolute terms and the largest percentage rise since 2010 (IEA 2022). Moreover, we cannot underestimate costs and consumptions in terms of energy and limited natural resources used as components in hardware and data centres' construction and their subsequent disposal.

The above concerns instigated retroinspection of the EU-funded project concerning CH digitisation in the past years. The European Commission funded at least 110 projects that produced or involve 3D heritage data. Conversely, only a few of them released the raw data, concretely contributing to an independent scientific debate. It is worth noticing that, in the new funding scheme Horizon Europe, the European Commission is increasingly relying on Open Science, Data Sharing and Open Access. For instance, by including Open Science practices in the Excellence section of the project or by requesting a data management plan where data sharing should follow the principle "as open as possible, as closed as necessary" and be in line with the FAIR principles. Nevertheless, how have digital heritage projects been acting so far?

Moreover, this research points to underline the importance of an existing web tool, such as Zenodo, towards a more sustainable approach to 3D datasets. Zenodo is an online repository, launched by OpenAire and CERN in 2013, now hosted at CERN and already in use by scholars from all fields of science. The repository was specifically designed to help researchers from smaller institutions to share results in a wide variety of formats, allowing them to upload raw data and publications secured by a DOI number (Sicilia, García-Barriocanal, Sánchez-Alonso 2017).

This research argues that at present, in this historical period, this borderline situation represents the right moment to go through a methodological discussion on what must be digitised, how to preserve the recorded data and, above all, why is it fundamental to maximize the impact of heavy 3D data sets, fully exploiting their potential to foster hyper-disciplinary research. Re-thinking the life cycle of 3D datasets is at this point a mandatory task in order to modify an alarming trend.

3. Materials and method

The analysis started from an online survey of the Community Research and Development Information Service (CORDIS) website. CORDIS hosts info, objectives, and results from all the projects funded by the EU's framework programmes for research and innovation and the platform is managed by the Publications Office of the European Union (https://cordis.europa.eu/about/en). The survey focused on the EU-funded projects that explored heritage and produced 3D data, either as a final output or as a starting point for a broader process. Therefore, as a first step, a filtered selection of all the projects was made through the search tool available on the website, using two main strings of words: "3D heritage" and "laser scanning digitisation heritage". The search resulted in 188 projects selected in total between the two combined textual strings (https://cordis.europa.eu/search/en, accessed on 05/01/2023).

All the datasets were downloadable and offer a rich set of information about each project. Hence, as a second step, the filtered results were downloaded as an Excel sheet, and the attention was drawn to three main elements:

1) if there was any reference to 3D data sharing, accessibility or sustainable management in the project's short description and objective on CORDIS;

2) if the 3D datasets produced during the project were made available for download and not just uploaded for web-based visualisations;
3) if the external link to the project's website, usually available on CORDIS, was present and still active. This third element, apparently less significant, is a key indicator of how the concept of digital sustainability was approached. Maintenance cost and content creation are two factors usually underestimated but they are the two main elements against content fragmentation or loss.

The third step involved an analytical review of the full datasets implementing the recording scheme of the downloaded Excel sheet with 3 new columns for the 3 factors previously explained. For each project, the information reported was checked, both on the database and on CORDIS, and the new data were filled in. Of the 188 projects initially filtered, 110 (58%) were really pertinent to the Heritage and 3D data production topic (Fig. 3) because of directly approaching or mentioning it. While the 78 labelled as 'non-relevant' (41%) were a heterogeneous group of projects which were neither connected to the CH sector nor openly stating on CORDIS any kind of interest in 3D data production (even though some did) or 3D data sharing.

4. Results

From the 188 initially filtered projects from CORDIS, a final group of 110 relevant projects was selected because they directly or indirectly produced 3D heritage data. Among these only 35 explicitly mentioned data sharing on the project's resumé on CORDIS, accounting for 31% of the relevant projects.

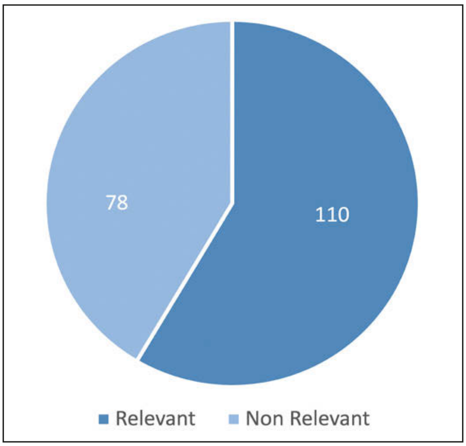

Fig. 3 – Chart that shows Relevant and Non-Relevant projects filtered from the research.

Furthermore, an in-depth analysis revealed that 8 out of 110 projects (7%) provided downloadable 3D data but not necessarily the raw data. In only one case there was specific mention that the 3D models production started from already existing datasets. If the projects classified as relevant but without an explicit reference to 3D data sharing are taken into account, the percentage slightly decreases to 6% (12 out of 188).

Just 3 of the 8 projects made the data accessible to all without constrictions. The other 5 showed different levels of restrictions, such as quantity or limited access to the platform for the download (Fig. 4). The usage of Zenodo for sharing a 3D point-cloud registration is recorded only for a project with a 2023 end date. Fig. 5 shows how the distribution of projects involving 3D heritage data has changed in recent years. It reveals a very positive trend that reached a quantitative peak in 2018-2022 with 13 projects. It is difficult to foresee but looking at the data collected so far, the trend should maintain its positive growth. It is also worth noticing that from the 188 projects analysed, 96 maintained an active link directed to a website, which accounts for roughly 51% of the total amount (Fig. 6). Even if, among these, 9 links redirected to a non-dedicated or official project web page (i.e., Facebook or ResearchGate pages) or the website of an institution which did not report direct mentions about the relative project (i.e., University's homepage).

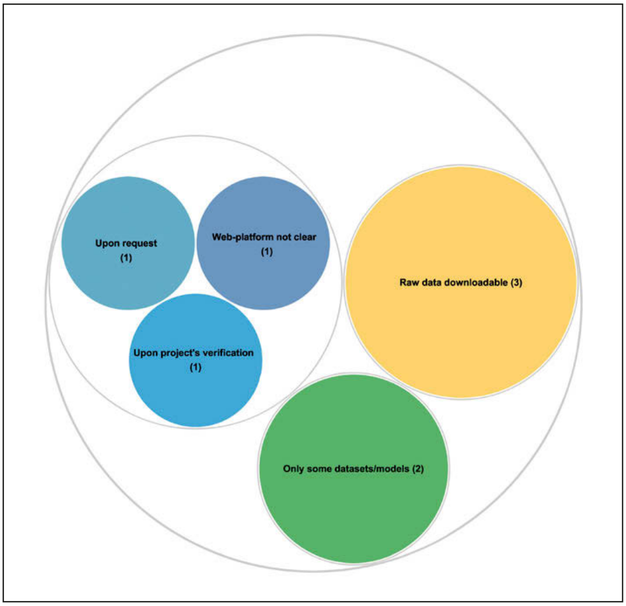

Fig. 4 – Chart that shows levels of access restriction to 3D data download.

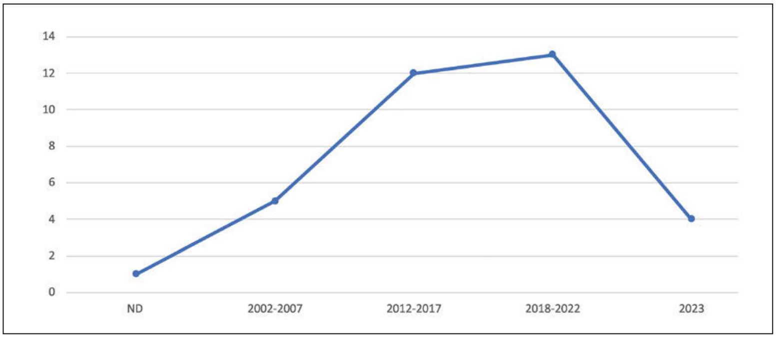

Fig. 5 – Graph that shows the trend of projects approaching 3D heritage data production and data sharing.

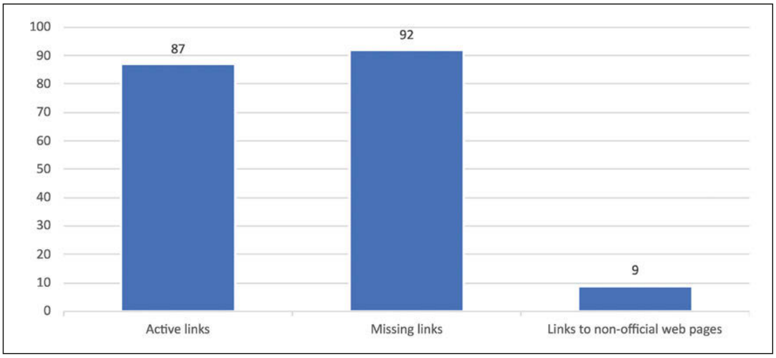

Fig. 6 – Chart that shows the proportion between projects with an active weblink and projects without.

5. Discussion

Starting from a general overview of some of the long-standing problems that have been affecting Digital Archaeology in the last 20 years, this paper wants to openly address some of these criticalities by looking at how certain alarming trends are currently affecting our approach to Digital and Digitised Heritage at European level. The analysis corroborates the idea that a generalised lack of 3D raw data management plans is forcing an unsustainable approach to heritage digitisation processes.

The data collected reveals a discontinuous trend which appears unsatisfying if compared with the number of EU-funded projects that produced 3D datasets. It is evident a lack in terms of 3D data sharing whereas only 8 projects out of 110 have concretely released some of the datasets produced. Another evident trend that points to sustainability issues is websites statistics: only 51% of the total projects, 96 out of 188, have maintained an active weblink on CORDIS. These patterns underline two different but entangled issues of digital obsolescence, and they both represent a threat to sustainability and preservation of our Digital Heritage. On one side there is an under-exploitation of datasets produced through community funding which will inevitably lead to one of the scenarios described in the introduction; on the other, the risk of web disappearance is a tangible threat. The lack of projects' web footprints represents a loss for the whole community. While the latter is a concern less related to the main goal of this paper, the statistics derived from data sharing are more alarming when it comes to Digital Heritage and research purposes.

It is indeed promising to notice that an ongoing project has already uploaded through Zenodo some of the raw data produced. However, it is undoubtedly mandatory to re-think the way in which, as European community, we approach the preservation of our Digital Heritage as much as the documentation of our physical heritage. It is true that the solution offered by Zenodo at European level is something that has been theorised and abundantly proposed by several scholars (Benardou *et al.* 2018) and is already in use by some EU-funded projects, mainly through a group created on the platform by OpenAIRE called European Commission Funded Research. Nevertheless, the lack of usage among Digital Heritage projects is evident. An example of how Zenodo could foster a more sustainable approach to 3D data is the project e-Archeo (https://e-archeo.it/, accessed on 02/01/2023). The project strongly relies on Zenodo to involve and create a dialogue among scholars through 3D models. Among the datasets available, point clouds, photogrammetry projects, orthophoto (Soriano 2022) and plans, are easily accessible as much as reconstructive 3D models (Bellelli *et al.* 2022).

Each dataset has a versioning Digital Object Identifier (DOI): this solution allows reproductions, updates, as much 'reversibility', data validation and citation (Koller *et al.* 2009). Therefore, this system could strongly rely on community-led quality control: the more a dataset is used the more it is analysed by the scientific community, and the more it becomes reliable. Re-use is a crucial step towards digital sustainability. A sustainable approach to CH digitisation should be based on both data selection and digital continuity, those are two recognised key factors to approach the issues of maintenance and obsolescence. Data selection implies a clearly defined set of selection principles, which are still an open question. Nevertheless, the value of the content and its potential high significance for future researchers should be prioritising factors. Another key aspect is represented by digital continuity: it is undisputable the need to allow access to digital content that «may, for much of its life, be changing, and that change itself is a necessary part of that maintenance process» (Bradley 2007, 161). Survival against obsolescence is not granted, but the more a dataset is accessed and used the more the chances are that it could be updated at two different levels:

1) At a quantity level, with newly collected raw data. This, on one hand, implies a growth of the dataset's file size, but, on the other, also of the detail and quality of information and transformations that occurred to the subject documented. An example could be again the Notre Dame cathedral: combining Tallon's point clouds with 3D scans recorded after the fire would be undoubtedly a fundamental dataset enrichment.
2) At a usability level, in terms of data format and/or software version. As software and data formats change continuously and at different speeds, re-usability allows files to be constantly updated from and for the community.

This could lead to a form of data sets' 'self-maintenance', where the broad scientific community' responsibilities towards 3D data are clearly defined and mainly based on providing reliability and update through active usage based on a DOI versioning system. The more the scientific community grows the more the whole system is able to sustain itself. Among the side effects that such a system would have are data transparency issues. Reliability and transparency are two strictly entangled concepts. Once the entire process of digital production is replicable because it is possible to deconstruct and re-construct each step, then there will be the premises to counterbalance 'digital faith': that instinctive reaction of trustworthiness that a Digital Heritage model, as a product of highly specialised computer graphic elaborations, often generates. Combined these two factors, re-usability and transparency, could drastically change the currently unsustainable digital life cycle, they could even become a research booster. The possibility to assign a DOI to a dataset, and consequently to create a direct link between data, author, dataset transformations and hypotheses or reconstructions, is not fully exploited so far. It could be a huge advantage for public institutions, such as museums or archaeological sites, to have the data protected with scientific attribution but still accessible to researchers and in the position to stimulate new projects' ideas. Data accessibility is the key against 'digital faith'.

This approach is being adopted by the whole Extended Matrix Initiative (Demetrescu, Ferdani 2021), working on developing an open source tool that has the potential to bridge the gap between physical and hypothetical. The EM tool is currently the solution that is closer to answer to some of the London Charter's instances and is doing so paradoxically by reversing the canonical usage of 3D models: turning 3D data into a step of a broader heuristic process and not as a final product, using 3D visualisations to display and link hypotheses, reasonings and sources. In short, thinking differently about 3D data as a dynamic resource for the community. "Visualisations as provocations" as Haynes proposed. On the topic, the approach applied by the ERC-funded project Rome Transformed appears very promising. By re-adapting a web platform developed by Dr Marc Grellert (http://sciedoc.org/, accessed on 30/03/2023), they are working on connecting and making reconstructive renders, digital visualisations and underpinning sources open to the public (Haynes *et al.* 2021). By doing so on a multi-layered and challenging case study, such as the eastern Celian area in Rome, they have the potential to impact the broader scientific community, empowering researchers and fostering new researches.

The cases presented so far show how processes of availability and transparency of sources are leading towards a necessary shift. A methodological shift, that is directing the focus on considering 3D models as raw data more than a finished product. Such a process must start, at least at the European level, from community-funded projects. Those are the role models: as projects that obtained major funding, they have the possibility to define a new trend in terms of outputs and methodological approaches, which, ideally, will then be reused by other research institutions and re-adapted by private companies and turned into industry standards. This must include a specific digitisation strategy with a clearly defined methodology and objectives.

The need to plan in advance and decide why we need to produce 3D data and how to share them is fundamental for turning the whole process into a sustainable practice, while considering digitisation as both the project starting point and its end result will inevitably lead us to be possessed by the tools and not in control of the workflow. Even though it refers to quality standards in thematic analysis applied in psychology, the methodological warning expressed by V. Braun, V. Clarke (2020, 2) is very relevant. The balance between adopting methodological standards and succumbing to proceduralism or 'methodolatry' must be found in «understanding what the procedures are, what they give you access to, and that these are tools for a process, rather than the purpose of analysis, is important».

6. Conclusion

The positive impacts that CH could have on communities' well-being through the promotion of a shared cultural identity and a broader sense of belonging is openly recognised in the European Green Deal. Furthermore, in the same document, the role of Digital Heritage is viewed as central to creating an inter-generational connection that could foster memory preservation and social inclusion. Therefore, as clearly stated in the ICOMOS Green Paper, the heritage digitisation program is considered in the upcoming future as a key step towards sustainable development. However, in the same Green Paper, the authors express sincere concern about the carbon emissions produced by large-scale ICT activities. If there is not a sustainable approach underpinning this heritage digitisation shift, how could digitised heritage generate a positive cycle?

From this point of view, it is very accurate how Dr Isabel Rimanoczy (2021, 10) approached the definition of sustainable activities, clearly stating that the concept of 'sustainability' should not be confused with just re-thinking pollution and waste policies. Alongside actions towards harm reduction, a sustainable approach must also focus on producing positive impacts. The Sustainability Mindset is defined as «a way of thinking and being that results from a broad understanding of the ecosystem's manifestations, from social sensitivity, as well as an introspective focus on one's personal values and higher self, and finds its expression in actions for the greater good of the whole» (Kassel *et al.* 2018, 7). Therefore, in approaching heritage digitisation we should look at the broader scenario and point to the greater good, at least at the European level as a starting point, developing and sharing a common strategy.

The Italian *Piano Nazionale di Digitalizzazione del patrimonio culturale* (PND) is an embryonic example of a necessary initiative at a national level, which at the same time must be actively linked to wider European digitisation-level standards. This is particularly felt at the paradata level, where the lack of shared standards could be very problematic in the future. Cases like, for example, objects digitised through 3D scanners develop high risks of data obsolescence due to the fact that each 3D scanner has its own property software and data format. Therefore, data maintenance and data survival are at high risk of becoming obsolescent in the medium-long term future.

Equally important to reducing harm is the generation of positive impacts: to do so it is fundamental to fully exploit the power of 3D data in connecting, as a bridge, researchers and specialists from different fields, fostering hyper-disciplinary projects. How much a vast restoration program of a historical building, could benefit from previously recorded 3D data, ideally produced by another research project conducted by architects or archaeologists? What if the same datasets, with minor updates, could allow structural engineers to perform structural viability analysis? In such a context, the benefits and the outputs derived from the multiple re-uses of the same dataset balance the costs of production, storage and maintenance.

As Digital Archaeologists we should look beyond the mere data production and the exercise in the style of choosing a certain tool or software. This is something that Jeremy Hugget (2015, 84) powerfully summarised by saying: «Digital Archaeology should be a means of rethinking archaeology, rather than simply a series of methodologies and techniques».

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ABSTRACT

In recent years, the exploit of 3D data use in Archaeology and the Cultural Heritage sector in general has caused an exponential multiplication of digital content that can be viewed on the web. Nevertheless, web platforms can display a concerning dualism: on one side some contents are over-represented with the same models uploaded dozens of times even inside the same platform; on the other, the inaccessibility or absence of proper 3D documentation for certain datasets limits the usefulness of the resources. As a result of substantial funding received (mostly from public institutions) and the volume of data produced by each digitization project, the final impacts on the broader scientific community remain limited. Starting from the analysis of data published about EU-funded projects by the European Union Commission on the platform CORDIS, this research approaches the delicate issue of the unsustainability of the current 3D data life cycle. The analysis of 110 selected projects revealed a disturbing pattern: even though the EU provided funds for many projects that approached in different ways 3D data diffusion or sharing, currently only 8 of them made the data accessible.