Developing and Maintaining a Web 3D Viewer for the CH Community: an Evaluation of the 3DHOP Framework

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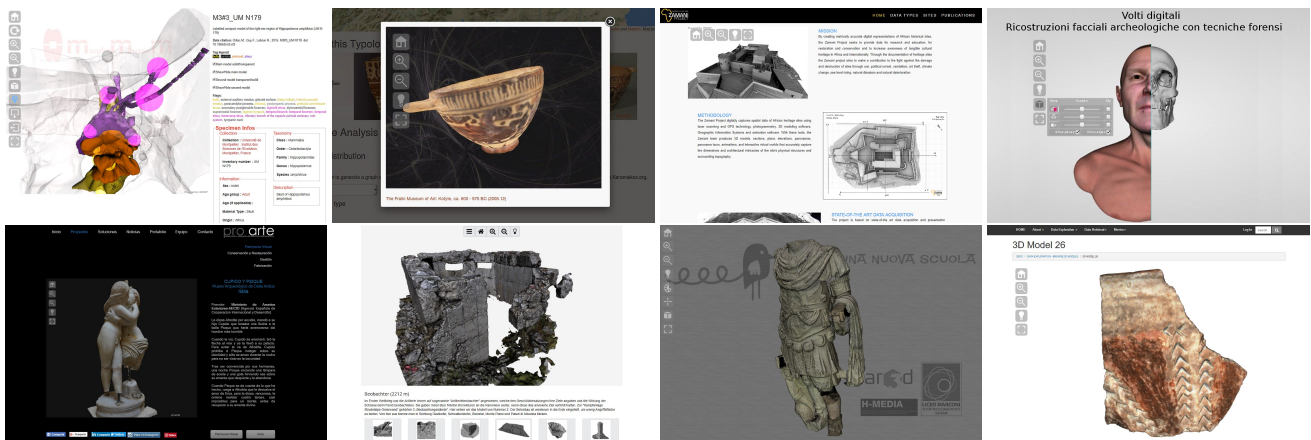
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Figure 1: *A collection of third-party projects developed using 3DHOP. From left to right, pictures from (first row): MorphoMuseuM [Uni14b, LO16], Fralin Museum of Art [Uni17b], Zamani [Uni14a], ImagoAnimi [Arc18]; (second row) ProArte [Pro15], South-Tyrol Heritage Department [Sou17], MuSm@rt [Ar317], DEFC [Aus15].*

Abstract
3DHOP (3D Heritage On-line Presenter) has been released 4 years ago, as an open-source framework for the creation of interactive visualization of 3D content on the web, aimed at the CH field. Transforming a research tool into a software "product" usable by the heterogeneous CH community is not a simple task and requires a significant amount of resources plus a specific design. This work presents the evolution of the 3DHOP system, and the complex relationship with its community of users, made of content creators, CH experts and general public. We will discuss the new features introduced, as well as the design and implementation strategy employed to maintain the software and make it usable by developers. We will evaluate the effectiveness of the platform by illustrating some of the applications built with 3DHOP either internally or by external users, as well as by presenting the results of a survey aimed at gathering the opinions and suggestions of the user community.

CCS Concepts
•Visualization → Visualization systems and tools; •Visualization application domains → Scientific Visualization;

1. Introduction

Since the launch of WebGL [Khr09] the status of the technologies for the development of Web3D applications evolved considerably, with a large number of experiences produced concerning both software development or user-driven production of content. Many tools and platforms have been proposed in the last few years to support the publication and interaction with 3D content on the web. These tools constitute an heterogeneous ecosystem, including "general purpose" systems, but also solutions more specialized on a specific technical field, a quite large group of commercial applications, but also a good number of research-based approaches. Restricting the focus on the peculiar domain of Cultural Heritage (CH), a good example of closed commercial systems is SketchFab [Ske14], a popular Web3D service characterized by an excel-

lent quality of the supported features and a quite large acceptance in the consumer as well as in the CH community; or the Smithsonian Museum X3D [Smi18], a tool developed by Autodesk to support digital museum specimens visualization. Together with these commercial solutions, there are also a number of academic platforms (a reference example is the X3DOM platform [BEJZ09]).

In April 2014 our lab released the first version of the *3DHOP* framework [Vis14] (acronym for *3D Heritage On-line Presenter*), which was described in an early paper just few months later [PCD*15]. 3DHOP is a platform designed to cope with the needs of the Digital Humanities community, supporting the creation of interactive visualization web pages and enabling the display of high-resolution 3D models. This paper can be considered a *post-mortem* discussion (post-mortem is a term, widely used in the videogames development field, that indicates a honest, often self-criticizing evaluation of a software) of the technical evolution of the system four years after its first release and, most importantly, of its impact on the community of target users. The latter point is treated here by presenting our development and support experience, by discussing some examples of interactive content or systems developed on top of 3DHOP, as well as presenting the results of a questionnaire that we have distributed to our users. Similar evaluations are not infrequent, in literature, like the CGAL library of computational geometry algorithms [FGK*00] or the CHER-Ob [WSA*18] tool. However, they are often more focused on evaluating the technical results or the performances of the analyzed tools, rather than the relationship of the tool with its user community, which is our main focus.

For the sake of conciseness, we do not include here a detailed description of the state of the art; we invite the interested reader to check the first 3DHOP paper [PCD*15] for a detailed review of alternative Web3D publishing approaches (and also for a more comprehensive presentation of 3DHOP), or the overview works by Evans et al. [ERB*14] and Potenziani [PCDS18], which present the state of the art of the Web3D world.

1.1. 3DHOP in a few words

3DHOP is a modular JavaScript library for the creation of interactive web-based 3D visualization. Exploiting the HTML5 WebGL component, it runs natively in browsers of all platforms, directly interfacing with the GPU. As various other solutions were available, we tried to direct our design towards some "open gaps" in the available solutions:

- **High-res 3D**: by using a streaming-friendly multiresolution scheme (the Nexus library [PD16]), 3DHOP can directly publish very large 3D datasets (> 100 Million triangles/points), and works with multiple large (>8k) textures. This differentiates 3DHOP from other existing tools, and makes it suitable for the hi-res digitized 3D models often used in the CH field.
- **DIY publishing**: 3DHOP is completely client-side; does not require specialized active server, just some space on the server. It is easy to add to existing websites, and in dynamic web pages. Users may host their viewers on their own servers and control the access to their data, that is an important for sensitive or restricted-access data (as often is the case in the CH field). It might run locally, making possible to create interactive kiosks.

- **Strong interconnection with the DOM**: we designed 3DHOP to make it interoperable with the rest of the HTML elements of the page, to make possible building truly cross-media interactive pages. By using JavaScript functions, the state of the viewer may be queried and modified runtime by the webpage, and user actions trigger calls to handle functions.
- **Multiple levels of use**: our belief was that, among the CH personnel building web-visualization, the vast majority would *not* be pure web-developers, and surely not experts in 3D Computer Graphics. So, by exploiting a series of defaults and self-configuring features, a naïve user can setup a basic 3DHOP viewer requiring no configuration at all. At the same time, a user with some familiarity with HTML and JavaScript may easily configure the 3D scene with parameters, add different tools, and interconnect the viewer with the webpage using JavaScript functions; finally, a skilled web developer may use 3DHOP as a *codebase*, to modify existing behaviors or add new features.
- **General Purpose**: the modularity of the tool makes possible to assemble very diverse web applications, and the basic distribution contains modules and tools that can be used both for dissemination and presentation to the general public, as well as for technical inspection, measurement and study.

3DHOP, as it often happens in the research domain, started as an internal tool for publishing 3D models on the web. As the development went on, we realized we were reaching a solid level of reusability and code cleanness. So, we were presented with the choice of taking the extra step of turning this tool into a software package to be shared with external users. As researchers, we are mostly evaluated only on the number and quality of our publications; this makes sometimes difficult to support the maintenance of a user-ready software "product". Our reason to carry on with this idea was that a tool used by multiple actors could result in a more stable instrument, useful to strengthen the use of Web3D and the position of our lab in the CH field and, finally, usable for finding new projects and collaborations. The effort of this kind of user-oriented development is not cheap, in the economy of a research group: working on 3DHOP we had a full-time PhD student, a part time researcher, plus another researcher working on the multiresolution core, not counting the occasional contribution of a couple other researchers. However, we can state that this design choice proved to be correct. Indeed, thanks to the more careful and structured development, the tool was easier to maintain and use also by ourselves; internal use of 3DHOP was successful and resulted in multiple projects and published papers. 3DHOP was the base of various collaborations with other external research groups and institutions, resulting in more financed and published activities. Moreover, the works of external users (see Figure 1) acted as a flywheel, helping the tool improving and spreading.

1.2. Building a community

Our lab had a previous experience with the development and distribution of open-source software, with the MeshLab tool [CCC*08]. In this case, despite the wide success of the tool (used worldwide, with more than three millions downloads), we always lacked a real connection to the user base, without a proper site, documentation and an aggregation place. We feel this lack of attention for the users

has limited a bit the potentiality of the MeshLab software. Only recently, with a YouTube videotutorial channel, a revamped website, GitHub code sharing, and a facebook page, we are somehow in contact with our users.

As 3DHOP was a product directed to a specific community, we decided not to make the same mistake, and to pair the user-oriented development of the tool with a more aggressive communication strategy. Our first concern when releasing 3DHOP was to support it via a series of collateral actions, aimed at building a community of users. We immediately started an official website [Vis14]; through this website, beside the 3DHOP core installation, we made available to the users a number of documented how-tos, a set of complete templates, a gallery with third-party examples, and the API documentation. The source code was made available via a GitHub repository. Some effort was made into cleaning and commenting the code, and structuring the project folders in a useful and tidy way. We also created a Facebook page and accessory social media accounts. We presented tutorials in different conferences, like CAA 2015 and Digital Heritage 2015, to directly reach a technical audience, gathering every time 20-30 attendees. In retrospective, another missing component could have been a forum, to promote user-to-user interaction and self-sustaining support.

This effort was not wasted: being reachable by the community helped us a lot in different aspects of our work. We have had numerous contacts over the social network's pages, both via comments and via messages. The website has been visited thousands times, and we have been reached by email by around a hundred users, asking support, signaling bugs, requesting features and, sometimes, proposing collaborations. The contact with the users, as explained in Section 2, was valuable in the development and support of the software. As we will see in Section 4, the users have appreciated this effort, but have also asked for more.

2. Evolution of 3DHOP

By comparing 3DHOP today with the tool presented in the original publication [PCD*15], it is possible to see the evolution of the tool through the many additions and improvements that have been introduced in these four years. Since its first release, we had a pretty defined roadmap for the expansion of the tool capabilities, derived from the experience gathered by the lab in many years of work in the CH field. However, the direction of development was also greatly influenced from the feedback from the user community, received via the Facebook page and through emails. In this design phase, the input of the users was extremely important, and often steered our decision process.

We have expanded the supported 3D data formats, adding the management of point clouds, of texture mapping (large texture, multiple textures), and the ability to use even larger 3D datasets. We have worked a lot in improving the Nexus multiresolution engine, both on data management and rendering. Beside being more efficient on large datasets, 3DHOP now uses a unified cache for all the 3D data, making a better use of the memory even with many high-res 3D models at the same time. Data compression ensures a smaller server and network footprint, and a faster startup. We have introduced new parameters for the configuration of the scene, cam-

era and appearance. Now it is possible to use transparency or solid-color, configure lighting and camera projection parameters, and the setup of a scene with multiple objects with associated transformations has been made simpler. For the user interaction, we have improved the functionalities of the available navigation modes (trackballs), and added new ones. New "technical" tools, like the point-to-point measurement, cut-through sections and pick-point coordinates have been added, to be used in those viewers developed to present scientific, metric 3D data to other experts. At the moment, we are improving the support of mobile devices, trying to cope with the often non-standardized way of managing touch input on mobile browsers. We are also starting experimenting with WebVR, to expand towards VR/AR devices (even if at the moment it seems impractical to adapt the current scene creation and interaction methods to work both on screen and VR, and it will be probably necessary to introduce a different set of components for scene creation and interaction/navigation).

Bug-fixing and adapting to the rapid change of the web platforms was also a concern. The continuous update of browsers and small changes in the behavior of WebGL required quick fixes to the 3DHOP tool. This was necessary to provide a stable and performing tool to the community. Various bugs have been spotted and pointed out by the users community, proving again a good connection with the users is vital for the life-cycle of a software tool.

2.1. Design strategy

The development of 3DHOP strongly followed the suggestions from the community, and the requirements deriving from our experience in the field. However, all this input had be filtered out, in order to ensure a sustainable development, and to make this tool usable by a community of practitioners with diverse skill levels. To this aim, we followed some basic guidelines:

- **Ready to use components**: each feature should stand on its own legs, even without configuration, with a proper default behavior. The user may configure it using parameters and functions, to adapt it to specific cases, but the default behavior should "make sense". As no real standard exist in CH, when possible, multiple components with alternative behaviors should be provided.
- **Retro-compatibility**: all the previous viewers should work with the new code, when moving to a new version of 3DHOP. This means that, even though some features were largely improved with respect to the initial behavior, we tried to keep the initial behavior as the default one also in subsequent versions. This might sound counter-intuitive, but being able to just overwrite the old version with the new one is extremely useful for users, and outbalances this issue.
- **Documentation**: every time a new version is released, we update all the documentation, the examples and the tutorials. This took, sometimes, more work than the actual implementation of the new feature(s), but it was worth the effort, as the tutorials and documentation were kept congruent and updated.

While these guidelines helped shaping the development of the tool, and ensured the stability of the code and the usability of 3DHOP also by non-experienced developers, it is also true that they posed serious limitations on the kind of features that could

be implemented and supported. The more 3DHOP increased its complexity, the more the addition of a new functionality become complicated, due to the possible inter-dependencies with the rest of the code, the need to preserve compatibility with the past versions, and to fulfill the goal of not introducing changes to the semantic of the function calls and objects properties. In the various releases, it frequently happened that new features were firstly added as hidden, undocumented features, initially used only by our laboratory staff; and then they have been re-engineered to become compatible with the whole architecture, and officially added in the next release. Some of these added features have remained hidden, undocumented, as they "break" the above mentioned rules (i.e. they might require extensive expert configuration, or, when used, they might interfere with some other functionality).

The users community was sometimes used, in these situations, as testers: we selected some user(s) among the people that contacted us and were interested in that specific feature, and we gathered direct feedback on a test release. Some features were discarded and kept undocumented/hidden (e.g. the "rail" trackball and the oblique sections, both deemed too difficult to configure) while other were improved, finalized and added to the official release (e.g. the orthographic camera or the lighting control). The advantage of having real-world testers is significant, but requires time and a careful process of cherry-picking the users.

We are, however, about to hit a limit in this smooth and progressive evolution process. As said, this incremental design is becoming more and more difficult, as features interact with each other. One solution could be carrying out the current dual-layer strategy of having a coherent, well documented and easy-to-use tool for the general users, while adding new features in an underlying layer, to be used only by our lab and few selected users. Conversely, we may choose to discard some of our rules, and introduce conflicting and heavy-configuration-requiring features. The final option is to start a complete re-design and implementation of the tool, creating a brand new version, totally incompatible with the current one. Among these possibilities, it is highly probable we will carry on with this double-layer strategy in the near future, but will also start working on a better design and re-implementation for a future long term evolution of the tool.

2.2. Open source policy and shared SW development

The code of 3DHOP is open source for many reasons: it is the general practice of our lab, since being researchers we believe in sharing our results with the community; we do also believe developing and using an open source code might act as a guarantee of the scientific value of the data, as it is possible to verify that no hidden processing and tricks are applied to the data. Another good reason for sharing the code is that, exploiting a collaborative platform such as GitHub, it is possible to manage the source development in a truly shared way, providing a more usable codebase, but also having external contributions.

We have to say that, so far and in this case, the idea of having users contributing to the open source code failed completely. Indeed, in all the 3DHOP life time, despite we received notifications of localized code bugs (sent us via email, not through the GitHub bug reporting system), we just got a single code contribution. As GitHub is widely used among web developers, we expected to receive some bug reports and feature requests through this system. This could be due to the target community not being pure web-developers, but more CH experts with web skills, thus less expert on the use of these code sharing platforms. We know, through personal contacts with some users of 3DHOP, that some of them *did* modified the source code, adding new features specifically design to fulfill their needs; but they did not cared to share these modification with us. In this sense, the experience with 3DHOP is not much different from the one with MeshLab [CCC*08]; also in that case, the community was quite reluctant to contribute to the development of the tool. We were conscious that the lack of external MeshLab contributors was due to the poor documentation, the use of outdated source sharing tool, and the lack of a clear development strategy; so, we tried to correct the aim in the development of 3DHOP and of its community, but without a major success.

3. 3DHOP out in the wild

A preliminary feedback on how the potential user community has recognized 3DHOP can be implicitly extrapolated with a few numbers, such as the number of accesses to the 3DHOP website or the number of software downloads. We count around *40,000* accesses to the official website since the initial release in 2014 (around *800* accesses per month), while the 3DHOP package has been downloaded more than *3700* times (an average of *80* downloads per month). These numbers alone are just to demonstrate a good interest in our framework. But for a proper assessment we have to understand if the tool was really useful as intended. Presenting and studying some selected real-world examples can be helpful not only to validate our design choices, but also to evaluate in a more complete way its impact on the community of target users.

To date, we have mapped around *50* 3DHOP-based applications publicly accessible on the web, known because we had direct contacts with their developers, or retrieved via web search. This number seems inadequate, compared to the access and download figures. Possible causes for this discrepancy may be the difficulties to track the smallest projects or the cases where 3DHOP pages are build dynamically from web-apps, CMS or databases (not indexed by search engine), and the impossibility to conduct a census on off-line applications (like museum installations). Moreover, we are aware (through direct contact) of several research groups that are using 3DHOP as an *internal* visualization and working instrument, thus, without a final publishing on the web, or with the viewer only accessible via password in restricted-access servers. Following these considerations, we strongly believe that the amount of total projects developed using 3DHOP is reasonably much higher than 50. However, also considering these facts, there is still a gap of "hidden users"; a possible reason could be the general reticence in the CH field at sharing their data. This makes difficult to build a community, but we believe the trend is slowly changing.

As we said in the Section 1.1, 3DHOP was developed as a tool to be used both internally and by external content creators; thus, we have chosen to present some examples of real-world applications developed with 3DHOP, grouping them in two classes: one for the applications developed with our direct contribution, and one for the

solution designed and implemented by independent actors without our support.

3.1. Projects developed with our collaboration

The tool has been extensively used in our lab, to implement both general purpose viewers applied to single models and with more complex Web3D contexts (specialized trans-media containers for multi-models presentations). Being the developers, it was easy to exploit the whole gamut of its components, but also to actually modify its code, to enhance or extend its capabilities. Beyond the use of 3DHOP as totally internal tool, there were many instances of collaboration between our lab and external entities. These cases, in our opinion, are even more relevant for the framework evaluation, because even if they still see our direct intervention on the code, they can better show the 3DHOP flexibility and adaptability to technical infrastructures and publishing needs going beyond our horizons.

Adding a stratigraphic viewer to the ADS archive
Archaeology Data Service is a spin-off of the University of York that is providing a service of digital repository, cataloging and remote access to archeologycal data. In domains where 3D data is used for technical purposes, often digital archives require viewers specialized for their peculiar datasets. We collaborated with ADS [Arc16, GCD*16] to integrate 3DHOP at two different levels: as a basic viewer in their online repository, and as a specialized viewer for the visualization and study of stratigraphic excavation data.
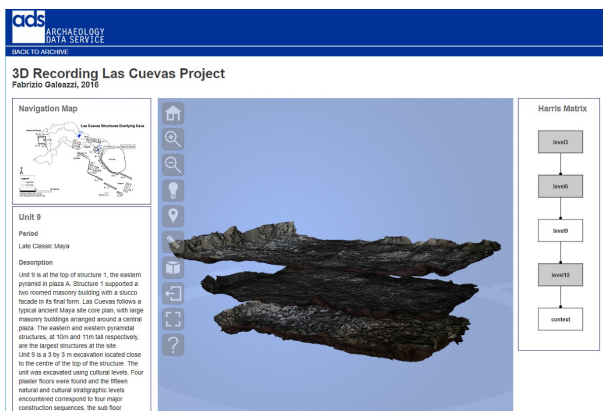

Figure 2: *The ADS "Stratigraphy 3D" interactive viewer showing three different layers of an archaeological stratigraphic sequence. To the right of the viewer is visible the HTML element implementing the dynamic Harris matrix which drives the layers visibility (picture from [Arc16]).*

The basic viewer does not offer many innovation in terms of interaction and visualization paradigms, but is interesting because it exploits the capabilities of the scene-creation mechanism in 3DHOP. As the definition of the scene and the basic configuration is based on a JSON structure, it was easy to dynamically build the viewer inside the page generated by the database query. Moreover, 3DHOP automatically adapts the scale, centering and navigation

parameters on the geometry of the scene, so, it was not necessary to configure view parameters of every single object

The ADS archaeological repository aims at documenting not only the single excavation findings, but also the whole excavation. This kind of aggregated data, consisting of a stratigraphic sequence of the archaeological site digitized over the time, requires an ad-hoc visualization strategy. We developed a 3D interactive visualizer based on the Harris matrix concept, which allows to explore a set of stratigraphic units in a single 3D scene (see Figure 2). Clicking on the different elements of the matrix, the final user can dynamically drive the visibility of the various stratigraphic levels, with the possibility to explore their spatial and temporal relationships. The viewer exploits the multi-object 3DHOP scene, and the selective visibility control, plus few of its built-in components (hot-spots, measures, sections). A custom-built element, used for sharing the current view via a parameterized URL, was added to complete the viewer.

Figure 3: *The "Alchemy in 3D" interactive viewer in action during the museum exhibition. Two of the four 2D interface elements superimposed to the 3D model are visible: the main menu panel and lighting tool component (picture from [Vis15]).*

An interactive experience for an exhibition at the Guggenheim
Differently from the ADS example, the "Alchemy in 3D" [Vis15, CPP*15] project represents an application case in which 3DHOP has been used to deploy both a museum kiosk and a web app. Commissioned by and designed with the Peggy Guggenheim Collection museum, the project has been focused towards dissemination purposes. Its aim was to exploit the high resolution 3D model created during the conservation and diagnostic campaign carried out on the famous painting *Alchemy* by Jackson Pollock, to create an interactive 3D presentation (on-site and on-line), so as to explain to museum public the gestures, actions and techniques characterizing Jackson Pollock's art.

Since 3DHOP is a client-side system, we had the possibility to develop a viewer accessible on-site at the museum (as a kiosk running on a local Web server) and on the Web (as a classic Web3D application running on a remote Web server) with almost no changes on the code. By exploiting the modularity of the framework, we choose to use very few interaction tools, to not overload the museum visitors with too much technicalities, and we setup a minimal

interface, suitable for a touch-based interface (for the kiosk) but still usable for the mouse input (on web). We used the 3DHOP hotspots to create the interactive elements. Custom components were developed to ease the navigation (the minimap, the modified trackball), and enhance the visualization (custom shaders). Web and kiosk applications have been exploited in the Guggenheim temporary exhibition "ALCHEMY BY JACKSON POLLOCK. Discovering the Artist at Work", running in Venice (Italy) from February to September 2015 (see Figure 3), totaling more than *180.000* visitors. Later on, the kiosk was used in a similar initiative at the Guggenheim Museum in New York (USA), while the Web3D app is still accessible today [Vis15].

The two examples presented differ in publishing purposes, target audience, and final result; but they have in common a project design that exploits the 3DHOP possibilities for building a highly-customized viewer enabling connections with other interactive/informative elements, internal or external to the viewer area. This vision, that goes beyond the concept of a simple and "blind" viewer, was exactly the target application we had in mind when designing the tool.

3.2. Independent, third-party projects

As said, the 3DHOP framework has also been used by many external content creators for developing their viewers. These applications are useful not only in providing a more accurate feedback on 3DHOP as a tool for CH experts, but also in acting as a benchmark for the examples belonging to the previous group. We analyze here a couple of these projects, in our opinion particularly useful in this comparison.

Building a web viewer for an archaeological archive

The "3D Cuneiform Project" [Uni18] is one of the most recent third-party initiative adopting 3DHOP. It is a joint project between several Irish institutions (the Digital Humanities Centre, the Maynooth University, and the Maynooth St. Patrick's College) to enable free online access to part of a large collections of cuneiform tablets in Ireland (sixty-five tablets in Sumerian language dated
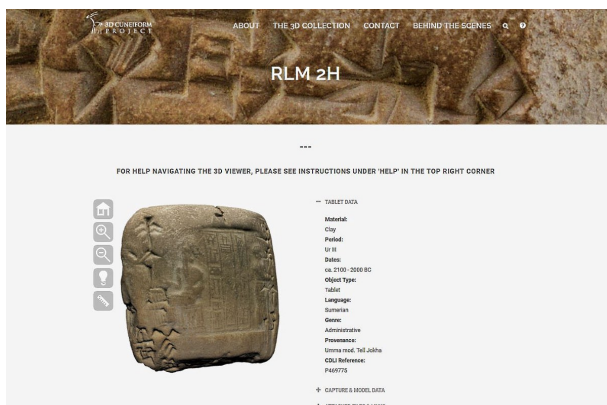

Figure 4: *Screenshot of one of the webpage composing the 3D Cuneiform Project archive. (picture from [Uni18]).*

3500 - 1900 BC, housed in the Russell Library at Maynooth University and recently digitized).

This Web3D publishing initiative has a scientific purpose, building a web archive pivoted on the 3D representation of the cuneiform tablets, allowing domain's practitioners to access, analyze and re-interpret the archaeological artifacts remotely. For each specimen, the archive presents a webpage (see Figure 4) containing an instance of the 3DHOP viewer and additional data related to the visualized artifact (i.e. information fields about the tablet and its virtual representation, plus some links to other multimedia resources).

Despite the 3DHOP viewer used for the 3D Cuneiform archive being a bit bare-bone, this project is interesting for the use of 3DHOP as a companion app for digital archives.
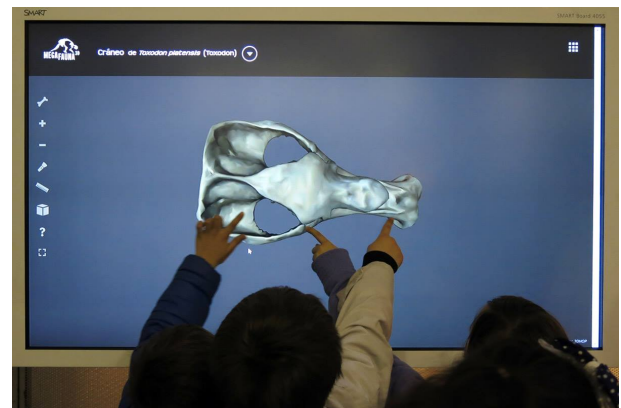

Figure 5: *The Magafauna 3D viewer, used as interactive kiosk, in action during a didactic event. (picture from [Uni16]).*

A paleobiological multimedia initiative targeted at kids

Similarly to the "Alchemy in 3D" example, "Megafauna 3D" [Uni16] is another initiative devoted to dissemination. Also in this case the viewer has been designed to be used at the same time as a web application and as an interactive kiosk. The specificity of this example are the target audience and some implementation details.

Developed by the Paleobiology Lab (Universidad de la Republica, Montevideo, Uruguay), with the support of the Venado Web team, the "Megafauna 3D" project is a fossil digitization initiative, a digital collection of 3D models and a series of didactic and interactive activities concerning paleontology. Its main aim is to involve a young audience in discovering the fossils of the animals that lived in South America 10,000 years ago. In this framework, the 3D application has been designed as an informative platform, that, according to the project's News section, has been successfully presented in a number of public events (see Figure 5), where the project team interacts with kids, using the viewers on touch-screen devices as an interactive teaching tool.

Because of the peculiarity of the project target audience, the viewer customization in this case study is quite simple. With a touch-enabled navigation and toolbar components, and personalized for being more engaging for kids, the interface is *deliberately*

minimal, and does not present complex interaction tools, to be easy to learn and simple to use, even for kids.

3.3. A matter of details

The latter projects represent two interesting and successful examples of independent content creators using 3DHOP in different ways and with different aims. Together with all the other third-party projects surveyed, these external examples demonstrate the positive impact of our publishing solution on the community.

Nevertheless, if we move the focus of our analysis from the relevancy of the final result to the level of exploitation of the features of our framework, then clearly emerge some other important trend about the 3DHOP usability that is worth to discuss. Just looking at the above examples, we can see that there is a significant difference between the potential of the framework (especially in terms of components personalization/creation and multimedia integration) and what the users are actually exploiting. Most of the projects we have encountered directly used the basic examples in the 3DHOP distribution, with little-to-none customization of the viewer, ranging from the "blind" viewers used as an interactive container for 3D assets, to viewers with only cosmetic changes to the toolbar or the graphic layout. Fortunately, it is also true that some projects *did* walked the extra mile, and used the tool at a much deeper level, also introducing new components to the framework. But, still, they are a small minority. For example, the "Emilia-Romagna Project" [Emi16], which worked on geological datasets, exploited a layered visualization similar to the ADS stratigraphic viewer, using a custom component for "vertical exaggeration"; or the "Cabinet de Curiosités 3D" solution [Mus15], which implemented the transparency shading even before we added it to the official release; or the "Casale di Balsignano 3D" example [Ins17], which procedurally uses the sectioning tool for creating more explicative visual bookmarks; or again the "Bonify" application [Uni17a], which couples side-by-side two viewers, for direct comparison between bones of different species.

Even if it is worthy stressing that a complex 3DHOP customization does not directly correspond to a more relevant project, the shown trend inevitably poses some questions on how much a tool like 3DHOP is really easy to use for the target community, or more simply, on what this community actually needs.

4. Users evaluation

Through social media contacts, email and conference/colleagues meetups, we were able to gather a significant feedback on 3DHOP, but it was sparse and unstructured. To gather some *direct*, *formal* evaluation from 3DHOP users, we run a survey. Looking for a representative but reliable base of respondents, we invited to the survey all the users which contacted our technical support service over the past 4 years (around one hundred contacts). Afterwards, to extend the number of participants, we also disseminated the survey through the 3DHOP social networks and website. To minimize the number of drop-outs, we went for a quite simple form structure: a short investigation about the user background and few close-ended questions on the basic issues to be evaluated (followed by a final open field for notes/suggestions).

In the 2 weeks running period, we received *41* valid responses (response rate of around *45%*, calculated on the total number of known email addresses). In some cases, as deduced by the notes, a working group responded as a single responder. The collected survey results are presented, in a rationalized and aggregated way, in the following set of graphs (see Figures 6 - 10). As some question accepted multiple answers, the final sum of the responses may exceed the number of respondents.

The first part of the questionnaire aimed at *profiling the content creators*. Concerning the 3DHOP target audience, the disciplinary background of the framework users seems to match the original expectations. Analyzing the trend in Figure 6, it is apparent that the users with a declared expertise in Computer Science / Graphics are a minority. In this context, if the large number of people involved in humanistic disciplines can be considered an expected data, as most of our dissemination was carried out in that field; the non-trivial number of respondents with a background in natural and applied sciences is quite surprising, but welcome, as it proves the versatility of the tool. However, we can look at this data as a good result, because 3DHOP has been designed to fulfill the needs of a non-technical user community, and tailored to the CH community.
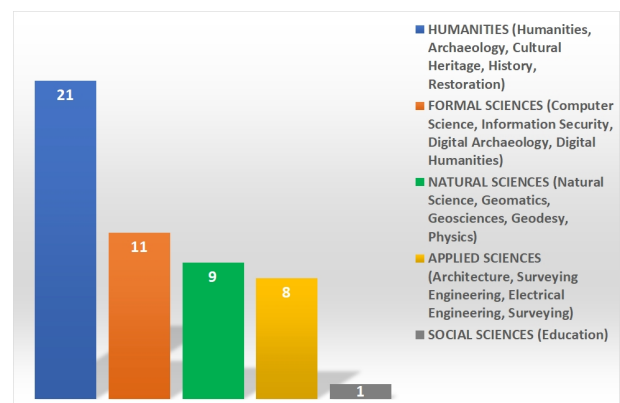

Figure 6: *Disciplinary background of users using 3DHOP to develop Web3D contents.*

The other profiling questions regarded the *main activity* and the *type of institution*. 3DHOP seems to cover the whole 3D data pipeline, as the vast majority of the polled users declared to be employed in the activities of "data acquisition", "documentation" and "visualization", strongly depicting a research-oriented scenario. Among the different organizations interested in Web3D, it is clear the dominant role of the academic institutions (university and research centers), cited as referring entity by the great majority (around 70%) of the survey participants. Although we are aware of various companies and commercial users working with 3DHOP, we got a minimal amount of responses from this side.

As we wanted to avoid to collect data from people that only skimmed through the tool webpage, we added a question regarding the *level of proficiency/use of 3DHOP*. The majority of the responders did use 3DHOP in some project (personal/internal/public), and almost everyone at least experimented with the examples.

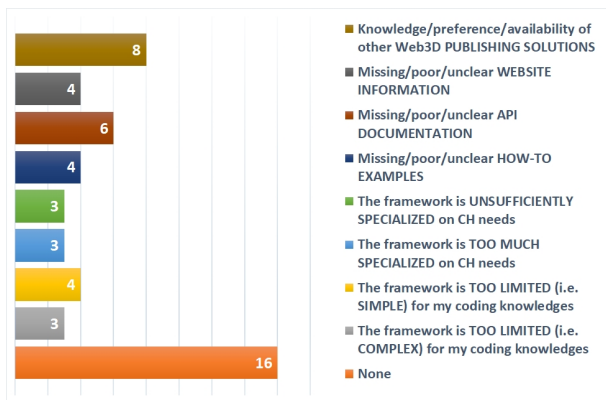Moving to the survey questions directly aimed at investigating

Figure 7: *Main obstacles approaching 3DHOP.*

the *3DHOP user experience*, we started our questionnaire asking the users to point out the *main obstacles* in *approaching* the 3DHOP framework. Figure 7 depict 3DHOP as an approachable tool, as a good number of users declared no obstacles in starting to use it. The availability of other solution *did* influence the way users approached 3DHOP: this was expected, and there is nothing we can do to improve this aspect. We are not seeking to overcome all existing viewers, but to develop a solution good for specific situations, so we are fine with people using multiple tools, as we are doing the same. As we will see also in other following questions, users are asking for more/better documentation and examples, this will be included in our to-do list. Interesting (and a bit funny) is the balance between the impression of the tool being "too general" and "too specialized", proving once again that balancing the technical complexity of a tool is always critical (and always criticized).
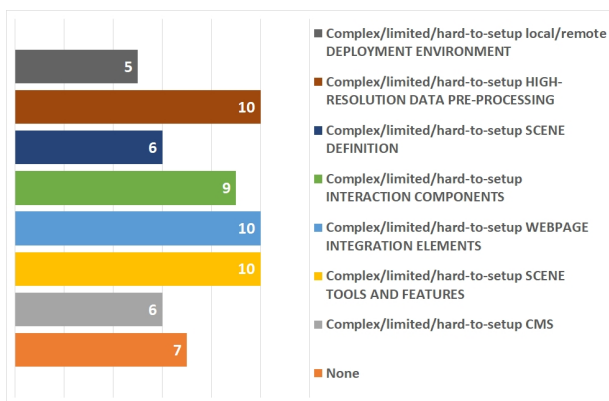

Figure 8: *Main technical issues in using 3DHOP.*

More variegated are the answers to the following question, asking to the content creators about the *main obstacles* in *using* the 3DHOP framework (Figure 8). We were happy to see that the *deployment* and *scene definition* received significantly less votes than the rest, and are thus perceived as the most accessible framework characteristics. Less encouraging are the many votes in the other categories, almost equally distributed. On a positive side, looking

at the notes/comments, it seems that few of the difficulties were due to features the users wanted to be added, or small incompatibilities that can be corrected (e.g. people wanting a dynamic scene *"Scene definition should be changed on the fly."*, or missing the multi-resolution converter for their specific OS *"Not all pre-process formats supported on Mac OS"*). In any case, we might have over-estimated the simplicity of configuration of some of the 3DHOP components. We will have to take care of this issue in the future, by helping the user in configuring these functionalities.

The questionnaire contained a question asking *which feature the users liked more*, and another one asking *which feature* the user most wanted to be *improved*. Considering that in these close-end questions the available options were the same, and also that the provided answers show an extremely correlated trend, we are showing the two datasets in Figure 9 using a visual representation useful in highlighting their similarities.
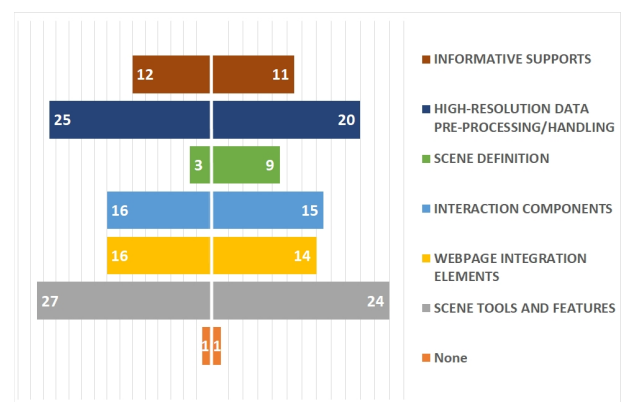

Figure 9: *3DHOP features more appreciated by users (left) and 3DHOP features that users would like more to be improved (right).*

The correlation between *like* and *want* is encouraging and might indicate that the users found the highly scored answers the more interesting features of 3DHOP, and want them improved because those are the more frequently used. Two features emerge more than others: the interaction tools (light, point-picking, measurement, plane-sections, hotspots, camera animations, visibility, transparency, etc.), and the multi-resolution engine aimed at high-resolution data handling (responsible for models streaming, rendering, compression, etc.). Even though we spent a lot of effort in providing documentation, the request for more information and support is still high; this trend is confirmed by few of the notes/comments.

The graph in Figure 10 presents suggestions on a ranked list of features to be inserted in future code versions. The request of better support for other classes of devices (mobile platforms, VR/AR head mounted displays), also asked in the notes/comments, is good news, as it is actually on our road map: the latest version is much more stable on mobile devices, and we are working on perfecting the touch interaction. VR devices are certainly the next logical step, but will require some more work. Two of the answers, "information management" and "trans-media mapping", are particularly interesting. While developing 3DHOP we decided to build a tool where the
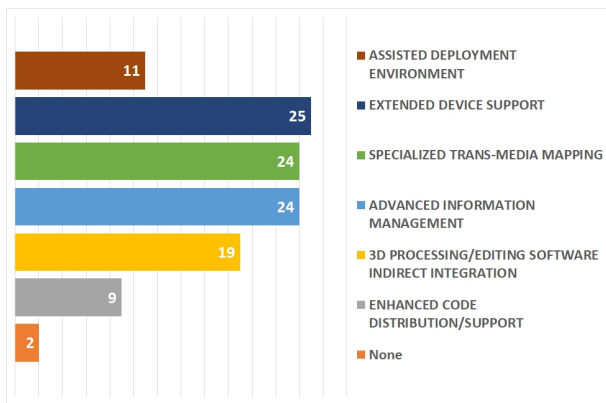
Figure 10: *3DHOP features that users would most like to see added in the future.*

semantics of the application had to be built by the content creator: i.e., we provided blank functions for the user interaction, and let the HTML developer to build the interface and the application behavior. This approach is extremely flexible, but probably requires too much expertise and a "programmer approach". As we saw that the built-in features have been used and appreciated, users seem to ask for more built-in functionalities to link data to 3D objects. Concerning the other highly voted answer, i.e. the integration in MeshLab-style software tools of components 3DHOP-related (like a converter for multi-resolution data, or an exporter for basic scene iframe), users are asking for an easier path from the 3D model to an automatic publication.

4.1. Comments

The survey was useful because it gave us a structured and formal confirmation to some of the ideas we gathered through impressions and direct contact with our users. The positive side of the feedback confirmed the validity of various choices in designing and developing the tool. The community we reached matches our initial target, and the set of features we invested the most time are the most appreciated (and requested for improvement/extension). Other answers pointed out some faults of our strategy, and gave us a somehow clear indication on where could be best to invest our future efforts. In accord with what we discussed in Section 3, a good portion of our users had trouble at using the deeper configuration features of the tool, and this can be part of the cause of the scarcity of complex viewers developed by third-parties. This is definitely a work direction we will need to cover in the immediate future. Moreover, according with both the answers and the notes/comments, users are asking for more built-in features, examples and templates.

5. Discussion and conclusions

In our initial plans, we decided to support 3DHOP for at least 5 years, to amortize the effort and to give the tool enough time to gather momentum and become used. Now we are at the 4th year and it is time for balance and decisions. As shown in the previous sections, since the beginning, we have planned the evolution of the

tool and looked after its use in the CH community. This attention has paid off, as it was possible to be more effective in the further development, use and promotion, conversely to what happened before with MeshLab, where we were somehow improvising.

5.1. A success story?

As it often happens with post-mortem analysis, having placed the accent in the previous sections on the things that have *not* worked fine, it might appear that this evaluation scored globally a negative balance. However, numbers in hand, we may say that after these first four year *3DHOP has been a success*.

The web and repository accesses, downloads, likes, emails/messages, and all the numeric feedback we gathered from the various channels showed interest and appreciation for the tool. Although, as said, many users remained untracked, the third-party projects and viewers were a confirmation of the fact that this tool is gaining a role in the CH community.

Concrete indicators of success were also the awards: 3DHOP got the second place at the Digital Humanities Awards 2015 in the category "Best DH Tool or Suite of Tools", while the "Alchemy in 3D" project won the Digital Humanities Awards 2015 in the category "Best Use of DH for Public Engagement", as well as a Best Paper award in the Digital Heritage 2015 Conference. The papers and projects involving 3DHOP were successful and well received.

5.2. The *Good* and the *Bad*

The effort spent in creating social channels, website, documentation, tutorials somehow paid off, as we were able to build a user community, that helped the development and spread of the tool. However we were unable to really gather a collaborative development group. Moreover, as mentioned in Section 2, the amount of publicly shared data was lower than expected from contacts and download statistics, probably affected by the protectionism often found in the CH community. The feedback we have received on the usability and quality of our tool is encouraging, highlights its strengths and how to best use it in the CH community. Thanks to the survey, we also have more structured indications on what we need to improve.

People used our tool, but not as completely as we wished; therefore, part of our design and development effort remained untapped. Looking at the way the users have employed 3DHOP, it is apparent that most of the users only used the basic viewer configuration, with minimal changes. It might be the case we overestimated the need for a deeply customizable framework: it was certainly useful for us, and for a handful of developers, but not for most of our users. Or, conversely, we overestimated the developing/programming background of our community. Apparently, the community needs a simple, ready-to-use viewer for huge datasets, usable with just a minimal configuration. 3DHOP can be used in this way, but most of its potential goes wasted. Given our initial idea, we gave less attention to this basic use of the tool; seeing the attention from our users, it might be the case to improve the simple viewer, to offer the community what they need. A possible response to these issue is also to work on supporting the publishing effort of the users. At

the moment, the creation of a viewer is completely manual, and each part of the webpage and tools have to be configured manually. This is clearly a bottleneck, for less experienced developers. Providing more starting templates, more specialized than the basic viewer but already configured may greatly help. Similarly, providing publishing and configuration wizards (as online tools or offline scripts) could help in supporting the users in more complex cases, and use all the advanced features of our platform.

Conversely, we may say the relationship of 3DHOP with the general public is quite satisfactory. The experiences carried out directly by us (e.g. the Alchemy project) and by external content creators (e.g. the Megafauna project) proved the validity of the tool as a dissemination tool. We do not have, yet, any formal assessment of the response of the general public, and we only have sparse feedback gathered from our projects and our users, but it could be helpful to think of an *instrumented* version of 3DHOP, to gather precise data on the actual user interaction.

Acknowledgements

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