Virtual Reality and Point-Based Rendering in Architecture and Heritage

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1. INTRODUCTION

Nowadays, acquisition technologies such as LIDAR (Laser Imaging Detection and Ranging) allow us to obtain high-precision georeferenced 3D scans of the real world in an easy and fast way. These types of datasets are called point clouds. These scanners not only provide position information but also color data associated to a point, yielding not only precise but also realistic looking 3D models by applying advanced point-based rendering algorithms. In disciplines like heritage, architecture or most engineering's, being able to have a detailed virtual representation of physical objects or places, in which you can measure or perform virtual walks, can be really important. Engineers can track and visualize from the desk the state and performance of the works, in addition to applying all kinds of computations easily and accurately. Archaeologists can store and manage exact digital copies of the pieces they are working with and make restoration plans; architects can represent the state of buildings and all the technical data too; urban planners can work on digital models of entire cities; and a long etc. This means a clear advantage over classic workflows, in which it would be necessary to go back to the field to examine a new area or perform certain measurements; this drawback is eliminated when you have a high precision 3D model of the site at your disposal.

Usually, the amount of data that results from the scanning of a big site with millimeter precision was not manageable by commodity hardware at once, and datasets would have to be decimated if an efficient out-of-core software solution is not available. Recent advancements in Computer Graphics and High Performance Computing (Gobbetti & Marton, 2004) (Allard, Lesage, & Raffin, 2010) (Jaspe, Mures, Padrón, & Rabuñal, 2014) have resulted in transparent out-of-core solutions that allow the user to visualize these datasets in real-time and perform measurements or other computations on them. Therefore, making it easy to spawn an algorithm that runs on the arbitrarily huge point cloud dataset, such as, for example, any kind of pre- or post-processing. Whilst these approaches on their own already present a big advantage and reduce the amount of work hours needed to perform certain tasks when obtaining and processing digital models for heritage or architecture, they can be dramatically improved by applying new workflows that take advantage of the possibilities of the most recent virtual reality technologies on commodity hardware, resulting in a higher level of immersion, interaction and realism when dealing with huge, highly detailed datasets.

Virtual Reality has been a hot research topic since the appearance of computer graphics, but lately there have been huge advances in the form of high quality and affordable commodity hardware, for example with headsets such as the Oculus Rift. The Rift is an upcoming head-mounted virtual reality display, which will soon be available for the mainstream, along with other similar new VR hardware: Sulon Cortex, CastAR, Altergaze, etc. These new devices also offer new possibilities in the field of Augmented Reality, up to now limited to tablets and smartphones as far as commodity hardware is concerned. In fact, Virtual Reality and Augmented Reality technologies have now achieved the point where it can effectively be applied in in conjunction with the aforementioned workflow will yield great advantages for architects, engineers and heritage professionals alike. This article shows new possibilities of application for Virtual Reality and Augmented Reality with massive point clouds in real world architectural and heritage workflows.

2. BACKGROUND

Point-based rendering has been around for a while (Levoy & Whitted, 1985), but lately there has been a renaissance in point-based graphics. This is a consequence of the increment in acquisition hardware precision, and the decrement of its cost. Examples of point clouds used in heritage applications can be seen for example in (Boehler, Heinz, & Marbs, 2002). This work highlights the potential in the usage of laser scanners and point clouds to document cultural heritage sites. Furthermore, in (Yastikli, 2007) we can see another example in which the aforementioned technologies are proved to be extensively useful in heritage applications. In addition, in (Doneus et al., 2011) a new low-cost computer vision approach to obtain point clouds in archeological excavations is detailed. These new methods, in conjunction with new low cost hardware that will be presented in the next sections; present a huge opportunity to improve current workflows in heritage research.

Point cloud applications are not only relevant in the field of heritage, but there is also great potential in applications related to architecture. For instance, in (Tang, Huber, Akinci, Lipman, & Lytle, 2010) point clouds are used to create as-built BIM models. This is normally a manual process, that can be significantly improved using point clouds and laser scanning. Moreover, even if a BIM model is not needed, it may be desired to document a structure using CAD for example. The work of (Mura, Mattausch, Villanueva, Gobbetti, & Pajarola, 2014) proposes a new approach for the segmentation and documentation of complex indoor environments from point clouds. Furthermore, another new application of point clouds that is gaining traction is 3D city modeling, in (Nebiker, Bleisch, & Christen, 2010) a new paradigm in city modeling called the *rich point cloud paradigm* is introduced. This new approach extensively uses point clouds with rich semantic properties in urban modeling, while maintaining a fully automatic procedure for capturing and generating these models.

As previously mentioned, in Virtual Reality there have also been substantial advancements that have brought costs down and improved the quality and capabilities of the hardware. Early applications of virtual reality already yielded benefits for heritage applications, like for example (Gaitatzes, Christopoulos, & Roussou, 2001). In this work, the authors analyze the process of creating immersive virtual environments for archaeology projects, arriving to the conclusion that they provide rewarding aesthetic and learning experiences. Further developments like (Bruno et al., 2010), dive deeper in the topic of 3D reconstruction of cultural heritage and virtual reality. They provide a complete methodology for digital archaeological exhibitions, providing guidelines for the development of VR systems for heritage applications.

In addition to heritage, Virtual Reality also has been proven useful in the architecture field. For instance, in (Bates, 1992) early applications of Virtual Reality are explored; being some of them related to architecture. Later developments such as (Stoakley, Conway, & Pausch, 1995) explore the use of an interface technique called *Worlds in Miniature*. It uses a head-tracked display with a handheld miniature copy of the virtual environment for user interaction. One of the tests performed according to the system, was its use as a design tool for a traditional architecture project, with mainly positive results. Moreover, more technical applications were explored in (Whyte, 2003). In this work, the authors explore applications of virtual reality in construction: design review, dynamic operation, marketing, etc.

These works on their own already provide new approaches to classic problems that improve their respective fields. However, in this chapter a new system and work methodology is proposed; which employs all these technologies together to improve current workflows in heritage and architecture. This research has been motivated because the integrated pipelines of such technologies have not been found and these technologies naturally complement each other.

3. SYSTEM OVERVIEW

All the applications of advanced point-based rendering in architectural design and digital heritage workflows described in the rest of this work rely on the software stack and commodity hardware described in this section.

3.1 Software

Interactive processing and visualization of massive point clouds acquired by LiDAR or other acquisition technologies arises multiple serious computational challenges, as much for managing the great data volume that results in a big data problem needing out-of-core methods, as for visualizing the datasets in a highly realistic and immersive way. All the workflows presented in this paper rely on a system architecture based on PCM (Point Cloud Manager) (Jaspe, Mures, Padrón, & Rabuñal, 2014), a novel middleware designed to manage arbitrarily huge point cloud datasets out-of-core. In addition to 3D geometric information, datasets may also include diverse heterogeneous data attached to each point: color, normal vector, material properties, temperature, etc.

PCM offers a simple API to make it easy to write applications for dealing with all this information out-of-core, providing facilities for making computations on the dataset or visualizing it. Relying on a hierarchy of software caches and a spatial acceleration structure, data in PCM is automatically transferred from a storage device to RAM or VRAM when needed, providing the possibility to be processed on CPU or GPU by user applications. Thus, PCM exposes a point cloud abstraction layer that allows programmers to write code to transparently exploit its out-of-core architecture. Figure 1, shows the system design behind the applications proposed in the rest of the paper.
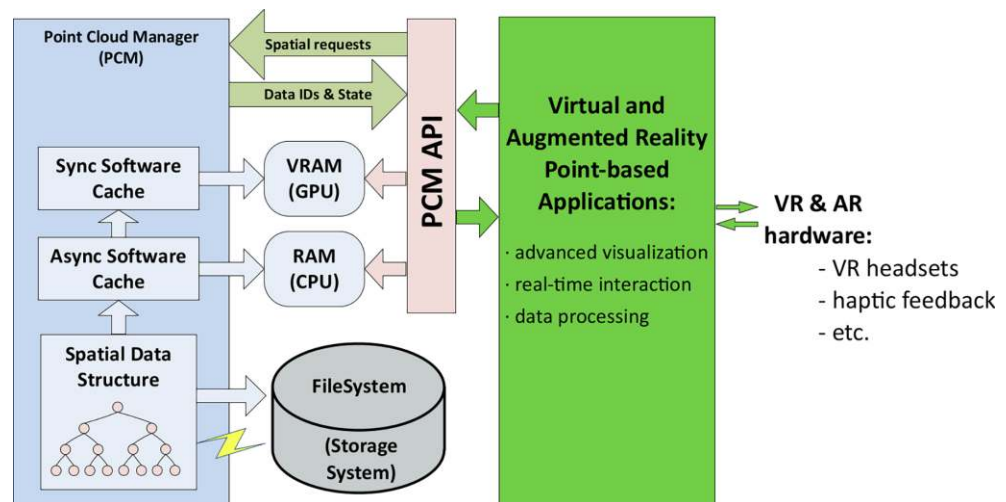

Figure 1. System overview of PCM-based applications.

PCM is developed following an object oriented approach and using the C++ language. The point cloud visualizer was implemented using OpenGL for visualization purposes and QT for the user interface. For GPGPU programming, we have chosen OpenCL, because of its inter-operation capabilities with OpenGL. This will allow us to process directly data that already resides in the GPU, without having to do expensive memory transfers. Because of the open nature of OpenCL, the software will be able to run on any graphics card vendor (AMD, NVIDIA or Intel) and the SO that the user prefers (Windows, MacOS or Linux).

The proposed framework offers tools for performing the following operations on point clouds:

- **Dataset conversion and management:** Tools for importing point clouds, format conversion, etc.

- **Acceleration structures:** This allows users to make faster point cloud queries.

- **Memory hierarchy:** Memory management tools (multiple software caches).

- **External interface:** Easily useable API for the creation of external applications.

- **Multicore and GPU support:** Tools for GPGPU and multicore processing on point clouds.

In addition, a Virtual Reality point-based renderer has been implemented using Unity3D. This prototype is compatible with the Oculus Rift, but has been developed using Unity3D for compatibility with future headsets. Furthermore, several plugins for the popular 3D design software McNeel Rhinoceros, have also been implemented. These plugins provide tools for point cloud exportation of surfaces and computational creativity geometrical design tools. The creation of these plugins aim to ease the impact of changes in current workflows, so that the employment of these techniques is feasible without much effort on behalf of the professional.

3.2 Hardware

As previously mentioned, Virtual Reality is far from being a new field in Computer Graphics but the recent appearance of VR commodity hardware has put within everyone's reach features that were usually available only in professional sectors, causing VR to become increasingly more mainstream. This has renewed interest in VR research and its multiple fields of application.

This new trend in VR commodity hardware have probably started when Google launched its Google Glass project as a new fresh perspective to what was labeled wearable computing, and that moved forward Augmented Reality capabilities found in smartphones and tablets. Since then, multiple VR headsets have been released or announced. We have chosen Oculus Rift for the prototypes described in this chapter since it is probably the most mature headset now in the market, so it could be already added in any engineering, architecture design or digital heritage workflow, as proposed in the next section. However, an eye must be kept on upcoming interesting projects such as Valve's HTC Vive platform or Sony's Project Morpheus. In addition, since one of our main concerns is the reduction of operational costs, it is important also to keep an eye on open hardware projects such as, the Razer OSVR. This is an affordable, open source headset, that has minimal distortion and could also be an interesting option. An honorable mention should also be made for the most affordable Virtual Reality headset, the Google Cardboard. This headset takes advantage of modern smartphone screens, to offer the user Virtual Reality in a simple and affordable package.

Besides immersive visualization, other devices may be useful to improve user experience when dealing with virtual or scanned models, such as haptic feedback gloves. Furthermore, new virtual interfaces could take advantage of the possibilities of systems like Leap Motion controller. This device is able to sense how hands move naturally and use computers in a completely different way. The user can point, wave, reach, grab, etc. This is especially interesting when using it in conjunction with Virtual Reality, since our brains already expect our hands to be in the virtual world; and not having them there takes immersion out of the experience. Haptic feedback devices take this one step further, allowing the end user to feel the virtual world. Be it through gloves or other types of input devices, like for example robotic arms with a pen-like structure on the end. This robotic arms offer resistance to the user depending on the type of material that the user is interacting with in the virtual world.

Last but not least, the other hardware piece needed in a point cloud based workflow is the acquisition device. Even though LiDAR scanning with professional 3D laser scanners is nowadays more affordable

than it was some years ago, LiDAR technologies cannot be considered commodity at all. There are, however, multiple alternatives to obtain point cloud datasets suitable for many scenarios, such as the BQ Ciclop, Microsoft's Kinect or by just using classic photogrammetry techniques. Even though we have mostly used in our prototypes datasets obtained by LiDAR and photogrammetry, other devices have also been successfully tested for scanning small and medium 3D models like the aforementioned Ciclop.

Depending on the needs of the project, a certain type of scanner will be chosen. For example, if a heritage site needs to be registered in 3D, a more advanced laser scanner may have to be used depending on the required precision. In contrast, if a small object needs to be scanned, one may be able to get away using a low cost scanner depending on the desired precision. When difficult areas without easy access need to be scanned, photogrammetry in tandem with drones can be used. This will yield high quality point clouds, which can be close in terms of quality to a more traditional terrestrial laser scanner.

4. APPLICATIONS

4.1 Heritage

A typical need of heritage researchers is sharing archeological information with colleagues, so that certain aspects of a site can be discussed between them. The ideal way of analyzing an archeological location would be on-site, in which it is natural to move around, make measurements, etc. As one may think, this is far from efficient if there is a big research community, and/or researchers are not close to the chosen localization.

This need can be fulfilled by using point clouds on their own with the right software, as a result, researchers will be able to share scanned models with ease. The first step in this task, will be the obtainment of the point cloud. This will be achieved onsite using a laser scanner, either terrestrial or mounted on a drone if the site is complex and the terrestrial scanner cannot reach every surface on its own. Using modern scanners, researchers will not only have position information for each point, but color and a myriad of other data. These scans are also extremely precise, reaching up to millimeter precision at a distance of hundreds of meters. As the reader can imagine, being able to make use of the full detail in these types of models, has clear advantages in comparison to decimating them to use them in common software.

Once the point cloud has been obtained, it can be distributed to the rest of the researchers. For this purpose, we will first detail a more classical approach. An FTP server or whichever method of distribution that is preferred, can be used so the cloud is accessible by all the researchers. Then, open source massive point cloud processing and visualization software like (Jaspe et al., 2014), can be used by the community to visualize the models with high quality point-based rendering (Botsch & Kobbelt, 2003). This can be done at no extra cost, without the need for the purchase of commercial software; and with several advantages that have already been mentioned. With this software, researchers will be able to perform measurements, create CAD models (Figure 2) for heritage site mapping, explore the models with total freedom, etc.
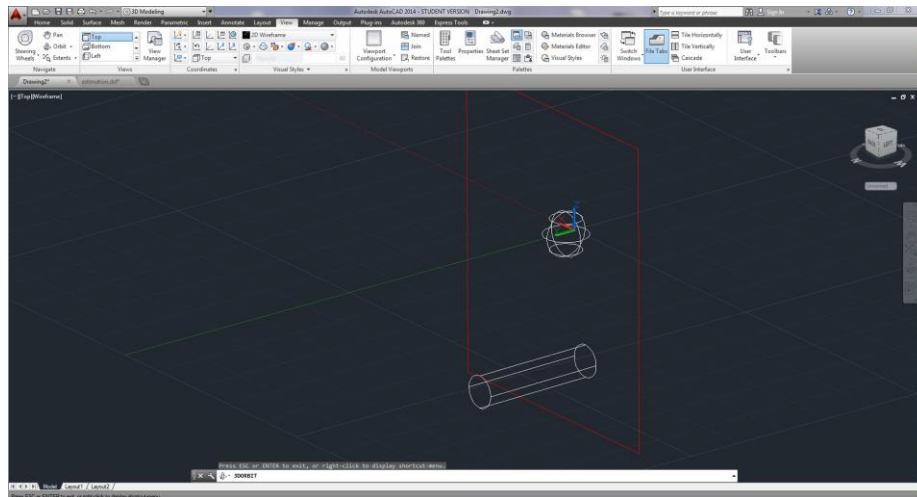
Figure 2. Example of the exportation of CAD primitives from the used point cloud software.

The second proposed approach, is a little less conventional. But, since nowadays web technologies have improved greatly; the software mentioned in the first approach can be modified to be used in modern browsers with WebGL. This will allow the 3D models to be stored in a central server, allowing researchers to view them directly in their browser; without wasting time downloading the models or installing extra software. This approach has almost all the same benefits as the previous one, but with the added advantage that the researchers will be able to communicate through the web application with ease. They will be able to annotate point clouds with important messages for fellow researchers, all in real time. In contrast, with the first method, this would have to be done through the usage of external tools.

Having achieved fluid visualization of the acquired point clouds for all the researchers in the community, the next logical step is improving the visualization experience and immersion. In order to accomplish this task, Virtual Reality is a natural fit. Since the main objective is making the researcher feel as if he still is present in the archaeological site, Virtual Reality headsets with nearly flawless head tracking are perfect for this case study. As we have described in earlier sections, the Oculus Rift has been chosen to create a prototype Virtual Reality point-based renderer for point cloud visualization. By using the Oculus Rift side by side with point cloud rendering software, researchers will feel as if they really are in the archeological site and will be able to explore the virtual model in a more natural way, thanks to the excellent head-tracking capabilities of these new Virtual Reality headsets. An example render using the Oculus Rift Virtual Reality headset can be seen in Figure 3.
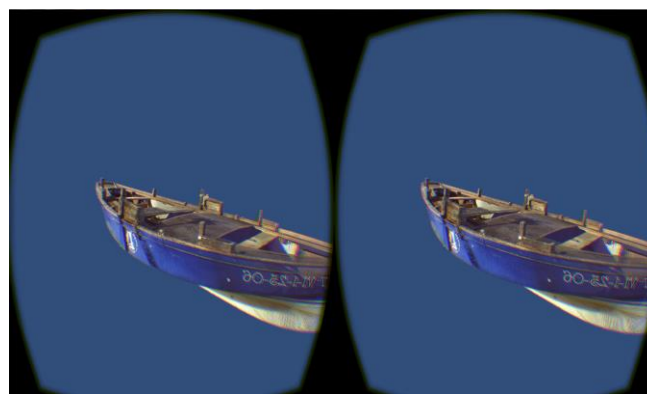

Figure 3. Visualization of a point cloud using the Oculus Rift headset.

Point clouds are especially well suited for this task because of photogrammetry. In a classical polygonal model, even with offline global illumination techniques, it is difficult to obtain realistic illumination results. With no effort or extra computational cost, point clouds have realistic illumination thanks to photogrammetry. This technique combines a laser scanner with high-resolution cameras, capturing the ambient illumination and making point clouds look like a 3D photo of the scanned area. This coupled with Virtual Reality headsets, creates a 3D experience that lets the researcher explore heritage sites as if he were there.

While trying to make the models look as realistic as possible, having a virtual model of a site means that we can aid the heritage professional when trying to identify subtle changes in the color or shape of a certain object. Sometimes, especially with ancient objects that have been exposed to the passage of time and the elements; it is difficult to discern certain details. Point cloud processing software can aid the researcher in the task of highlighting certain elusive shapes. For example, the user can choose a parametric primitive (plane, cylinder, sphere, etc.) and the software can color the region of interest in the point cloud so details can be better discerned. In Figure 4, we can see an example of such filter applied to an archeological structure interactively by the researcher, this is all performed in real time by the point cloud software. As we can see in the resulting image, it is easier to discern small details or carvings as a result of applying the filter.
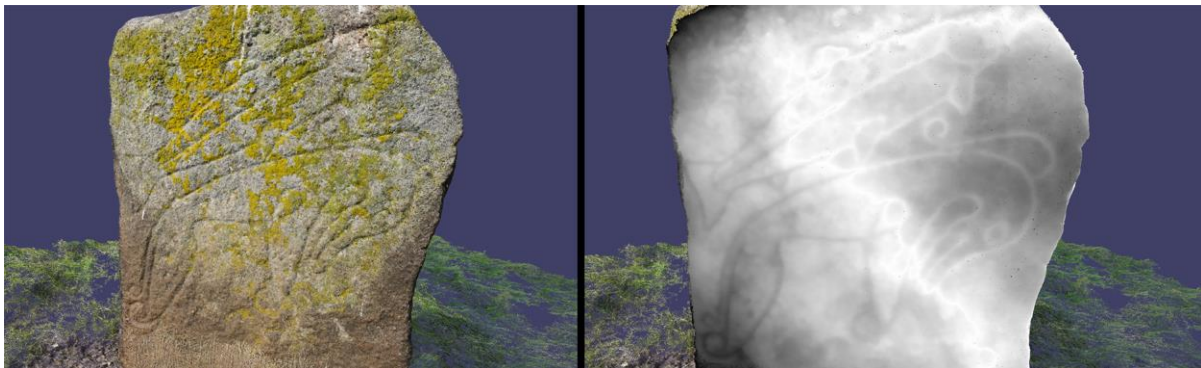
*Figure 4. **Left**: Unprocessed point cloud. **Right**: Region of interest of the point cloud with highlighted details.*

Furthermore, this software also allows researchers to interact with any kind of object in the scene with no impact on the real site, change its position, color, etc. Something that would be impossible in the physical archaeological site. This means that multiple point clouds can be combined, for example, placing objects found in different places or moved by any eventuality together. Readers can imagine the potential of this feature, researchers can reconstruct archeological sites virtually with little effort and no physical work. As we can see in Figure 5, two point clouds have been combined to create a new virtual site. In it, a dataset of an old statue has been placed in a point cloud of a heritage site.
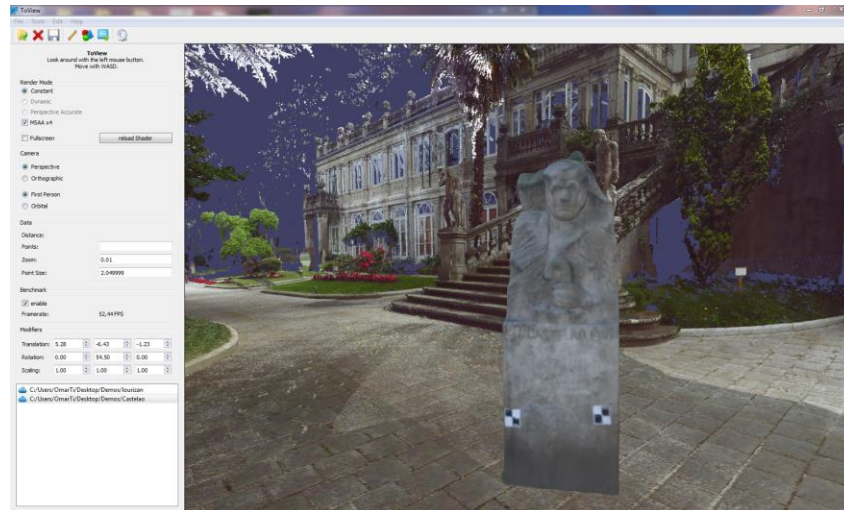
Figure 5. Virtual site created with the point cloud software that combines a statue and a heritage site.

Furthermore, it is not only interesting to visualize heritage sites, but it is also important to have an archive of the state of a certain site as time goes by. This will be extremely important for aiding in the conservation process and risk assessment. In this task, it is of outmost importance to make use of the full precision of the point cloud. When trying to measure distances, or when looking for structural problems, it is essential to take advantage of the millimeter precision that current laser scanners possess. This can be thought of as a trivial affair, but because of the massive nature of the resulting point clouds, it is not an easy task. As we have seen before, our proposed system has no problem with this task, since it has been designed to process arbitrarily huge point clouds. The measurement process can also be performed in real time by the end user, even in the biggest point clouds. In Figure 6, the result of the measurement can be seen in the center of the segment between the two selected points. Having detailed 3D representations with precise coordinates is key when catastrophes strike. These datasets are optimal for the reconstruction of archaeological monuments that were destroyed, like for example the two largest standing Buddha in Afghanistan. The Taliban blew up these two monuments in March of 2001, if they had been scanned and archived; it would be feasible to rebuild them.

Figure 6. Measurement of distances in the point cloud of a statue.

Moreover, having a good 3D representation of an archaeological site, is not only an advantage for researchers. If organizations are inclined to do so, they will be able to share this information with the public. A more general audience can, also use the same system that is used by researchers. This is a clear advantage, both in terms of the conservation of an archaeological site and the accessibility for the mainstream. Since Virtual Reality headsets like the Rift are now easily accessible to everybody, the public will be able to visualize the monument with maximum quality; but without the need for traveling and from the comfort of their house.

4.2 Architecture

Similarly, in the architecture field, there are clear advantages when using the proposed system. Generally, an architect employs 3D design software to create buildings or structures. One of the strengths of this method, is that the proposed workflow does not require the professional to change his design process if he does not desire to do so. Through the usage of point cloud export utilities, the creations of designers can be imported in point cloud software and manipulated with it. This has the potential to integrate artificially designed structures in real environments. In Figure 7, a computer designed 3D model is integrated in a real environment using the proposed system and workflow.

Figure 7. Shape designed in McNeel Rhinoceros and integrated in a real environment with our point cloud software.

Usually, the architect would have to wait until work had progressed a substantial amount to visit the work site and get a true feel for the design in the real world. With our proposed workflow architects can get a true hands-on experience from day one, and not only that, but the client can also give feedback to the professional at a critical point in the process; when no effort has been wasted and there is a lower cost if something were to be changed. Moreover, if a Virtual Reality headset like the Oculus Rift is used for visualization, the architect and client will be able detect architectural defects in a more natural way. Since the Rift has a screen with a wide field of view, as a consequence the brain of the user perceives scenes with a very high immersion factor. This means that defects that usually would go unnoticed in a normal

screen, when using a Virtual Reality headset will be easily detected. Whereas this is a clear advantage for the architect, it is also great for the client, since he will be able to also see the designed structure in a better way and make suggestions early in the construction process.

Furthermore, when work has started, the client and architect will be able to check on progress with no relocation needed. For this purpose, the use of a laser scanner by the construction crew to obtain periodic scans overtime is proposed. Since laser scanners have not only improved precision-wise, but also accessibility-wise. As a result, for the operation of these instruments, an expert is no longer essential. Scanners such as the Faro Focus3D possess touch screen input and are easier to operate than older scanners making this easier. With periodically captured point clouds and a Virtual Reality headset, both of them will be able to roam the work site but at their own pace and with no relocation costs.

Besides, using a messaging system like the one proposed in the heritage application of our system; is ideal in this situation. Clients will be able to make suggestions directly in the 3D model, and the architect will be able to react efficiently and change as soon as possible what the client wants, greatly simplifying current workflows. In addition, having archives of the construction progress on a work site not only allows the architect to detect defects, but also presents an opportunity for automatic detection of structural problems. Since the models generated in 3D design software usually are created taking into account the real measurements of the designed structure, and a point cloud is also registered with real position measurement values, this can aid in the early detection of structural issues comparing the computer generated model with the dataset acquired from reality.

To this end, it will be necessary to calculate a point-to-point distance. This is easily computed for points p_1 and p_2 with the following formula:

$$D_p = \| p_1 - p_2 \| \ (1)$$

For better compatibility with 3D design software, the point-to-triangle distance may want to be calculated. In this case, the minimum distance will be computed using the squared-distance function for any point in a triangle t to the point p:

$$D_t(u,v) = \left| t(u,v) - p \right|^2 \ (2)$$

For the following u, v values:

$$(u,v) \in S = \left\{ (u,v) : u \in [0,1], v \in [0,1], u + v \leq 1 \right\} \ (3)$$

The goal will be to minimize $D_t(u,v)$ over S. Knowing that D_t is a differentiable function, the minimum will happen either in the boundary of S or where the gradient $\Delta S = (0,0)$ (Eberly, 1999). Taking all of this into account, our system can now be used to let architects be aware about possible problematic areas. In Figure 8, an example of this feature is shown, points are highlighted in red when the distance to the artificially designed model surpasses a threshold.
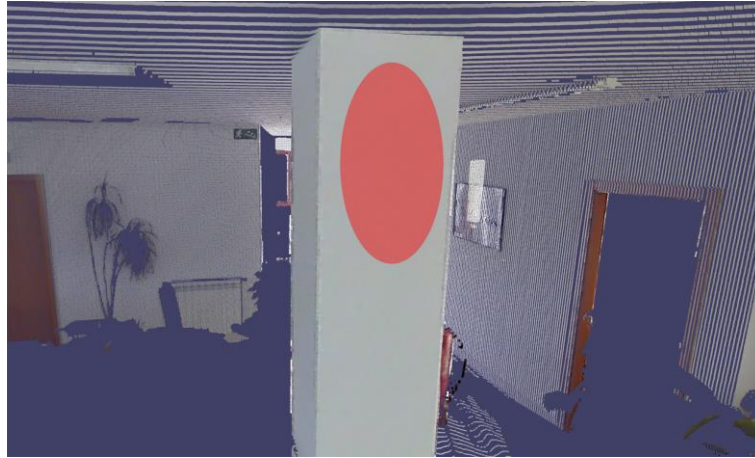
Figure 8. Column with structural defects highlighted by the proposed system.

Furthermore, if the architect would be inclined to do so, we propose the addition of several new elements to their design workflow. The first addition, is the use of Virtual Reality headsets in conjunction with plugins for their compatibility with current 3D design software. As a result, the designer will have better interaction with the designed models, being able to look around without using typical input devices like a mouse. This tool makes interacting with 3D design software easier for the professional, resulting in improved efficiency.

Moreover, we could include haptic feedback into this new workflow to allow for an even greater level of control and immersion. With such a tool, an architect would be able to "sculpt" structures in the design phase, as if he were working on the materials himself in a more natural way. This will improve the modeling capabilities and design tools available nowadays. Whilst this is a nice addition to a geometrical design workflow, it can also be useful when deciding the layout of a room. The user will be able to walk and move elements naturally, while being able to see the results as if he were actually present in the scene, but with no physical limitations.

Finally, new artificial creativity methods like (Pazos, Carballal, Rabuñal, Mures, & García-Vidaurrázaga, 2015) are proposed to be used, in order to obtain new and creative forms in architectural design projects. These new types of algorithms let the machine aid in the design process of the architect, by suggesting structural changes that the designer can choose to enforce. In Figure 9, we can see the result of applying the plugin that has been created in this work to a structure designed in McNeel Rhinoceros. As a last step, the developed plugins could be used to integrate the newly designed structure in real environments, letting the architect preview how it will harmonize with the environment.
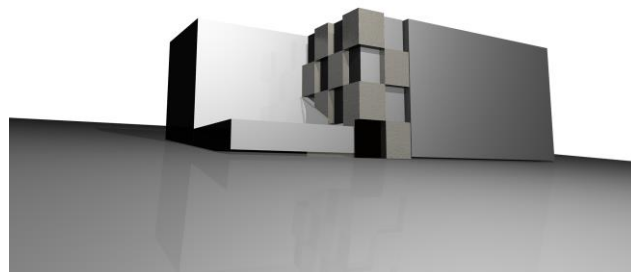
Figure 9. Structure designed with the computational creativity software present in (Pazos et al., 2015)

5. FUTURE RESEARCH DIRECTIONS

Primarily, one of the key future developments needed to implement the proposed workflow, is the modification of our current point cloud management backend to be more efficient. Quantization (Rusinkiewicz & Levoy, 2000) and data compression (Botsch, Wiratanaya, & Kobbelt, 2002) should be used to minimize network traffic. The efficient streaming of point cloud data, is a key step when trying to render point clouds over a network. In fact, this is especially important when trying to make the system compatible with modern smartphones, since their network connections are not as robust or fast as home broadband.

Another possible improvement, is the refining of the Level of Detail algorithm. A new technique taking into account human vision knowledge to improve the selection of kd-tree nodes, would increase rendering quality substantially. Moreover, implementing occlusion culling in the visualization system, could also yield benefits from a performance and quality standpoint. Refining these two aspects of the proposed framework, are of the outmost importance when thinking about point cloud streaming over mobile networks.

In addition, since the introduced workflow is trying to improve efficiency, it would be interesting to implement hybrid point-polygon rendering. Currently, several point cloud exporting plugins have been implemented in various 3D design programs. Nevertheless, ideally the professional should not have to convert artificial 3D models to point clouds so they can be used in conjunction with the proposed software. In order to be more efficient, the user should be able to import and visualize these polygonal models in our system with no extra effort needed.

As of now, a WebGL prototype has been implemented, but it needs to be refined. Firstly, it has been implemented using pure WebGL. Consequently, if a wide range of compatibility with browsers is desired; a 3D graphics library like, for example three.js, should be used. Secondly, the current prototype does not possess a messaging system. The implementation of said feature would be key in the communication between researchers or users. Thirdly, the implemented point-based rendering algorithm is really basic. Advanced point-based rendering algorithms like perspectively correct rendering (Zwicker, Räsänen, Botsch, Dachsbacher, & Pauly, 2004), already implemented in the desktop version, should be implemented in our web visualizer.

Besides, an Oculus Rift prototype has also been created. It has been implemented using Unity3D, which presently has no native support for point-based rendering. For now, point cloud support has been added manually, through the usage of multiple scripts implemented in C#. Furthermore, the integration of the proposed point cloud management backend in Unity3D could also improve the current prototype. A more elegant and efficient solution, would be the implementation of this Virtual Reality prototype natively using OpenGL. This would be faster and would allow the implementation of better point-based rendering algorithms, since the Unity3D limitations are not present.

6. CONCLUSION

Summing up, the inclusion of new tools like point clouds or augmented reality hardware in classic work-flows can substantially increase productivity, reduce costs and improve human interaction between professionals and clients. But advantages do not stop there, through the use of novel design techniques like we have introduced in this chapter, computer aided design is quickly evolving. As has been explained in the last sections, haptic feedback, Virtual Reality headsets and new computer creativity algorithms are changing how designers work. The computer is no longer a difficult tool in which the designer vision can be captured with unnatural human interfaces. These new input devices are bringing computer-human interaction forward, making professional work more efficient, easier and more natural.

In the past, processing highly accurate point clouds and hardware was expensive and not accessible to everyone. Moreover, scanners yielded huge point clouds that even proprietary software was not able to handle. Datasets had to be split in multiple files or decimated in order to visualize and manipulate them. In addition, since the datasets were simplified, the full precision of the scanners was not exploited. Nowadays, with advancements in point cloud processing, like the open source software used in our system and also low cost laser scanners, this is not the case anymore.

What's more, Virtual Reality has undergone a similar process. Headsets were expensive, and hardware and software were not up to the difficult task. Advances in low latency trackers, and the increase in resolution of small screens have pushed Virtual Reality forward and into the mainstream. Headsets like the Oculus Rift or others from its competitors will be widely available at reasonable prices in 2016. These technologies will certainly revolutionize the display and 3D market, with new immersive experiences.

However, a completely immersive and ground breaking Virtual Reality experience, will also require haptic feedback input devices. In order to not only have a great visual experience, but also improve the way we interact with computers, these devices hold the key. Therefore, to truly have a fully immersive experience and boost geometrical design tools forward, there will also need to be advances in the field of human-computer interfaces. As it has been shown, efforts are already on their way in this aspect too. This is why, Virtual Reality is going to see a really strong push forward in terms of public acceptance. These tools make relocation costs disappear and the idea of not having to wait until a project is finished to see the final result a reality.

Furthermore, through computational creativity algorithms, the machine is no longer an impassive actor in the process. It is able to aid the designer, while not making its job obsolete. These algorithms offer the designer a range of computer-generated structures from which to choose, and with input from the designer keeps on creating refined structures until achieving the desired result. This is an especially difficult task for a computer, since as Edward de Bono said, "Creativity involves breaking out of established patterns in order to look at things in a different way". A computer is a machine that can process a massive amount of patterns in a fast and efficient way, but without breaking them in any way. Devising strategies for achieving creativity is not an easy endeavor and sometimes requires some external help as in this case study.

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KEY TERMS AND DEFINITIONS

Point cloud: Set of vertices or points in a three-dimensional coordinate system. These vertices are usually positioned in 3D space and have a set of coordinates (x, y, z). These sets of points normally are representative of the external surface of an object.

LiDAR: Remote sensing technology that measures distance to a target by illuminating it with a laser and analyzing the reflected light.

Out-of-core: Type of algorithm that is designed to process data that is too large to fit into a computer's main memory at one time. These algorithms must be optimized to efficiently fetch and access data stored in slow secondary memory such as hard drives.

Rendering: The process of generating an image or set of images from a 2D or 3D model, by means of computer software.

Photogrammetry: The science of making measurements from photographs, especially for recovering the exact positions of surface points.

Virtual Reality: Which can be referred to as immersive multimedia or computer-simulated life, imitates an environment that simulates physical presence in places in the real or imagined worlds. Virtual reality can recreate sensory experiences, which encompass virtual taste, sight, smell, sound, and touch.

Haptic Feedback: Haptic technology, haptics, or kinesthetic communication, is tactile feedback technology which recreates touch by applying forces, vibrations, or motions to the user. This mechanical stimulation can be used to aid in the creation of virtual objects in a computer simulation, to control such virtual objects, and to improve the remote control of machines and devices. It has been described as "doing for the sense of touch what computer graphics does for vision". Haptic devices can incorporate tactile sensors that measure forces exerted by the user on the interface.

Computational Creativity: Computational creativity (also known as artificial creativity, mechanical creativity or creative computation) is a multidisciplinary endeavor that is situated at the intersection of the fields of artificial intelligence, cognitive psychology, philosophy, and the arts. The goal of computational creativity is to model, simulate or replicate creativity using a computer.