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Tactile Interaction in an Ancient World on a Web Browser

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***Abstract*: Complete involvement of learners in their learning environment has the potential to promote better absorption of knowledge, through pedagogic mechanisms such as experiential learning. To support such approaches within the domain of cultural heritage, this article discusses the deployment of tactile perception as a part of an ongoing development of a multimodal learning platform to complement learner interaction with virtual artefacts promoting more real experience and active reflection.**

By stimulating visual and tactile perceptions, learners' engagement and interest in the learning process can be sustained through "first-hand" interaction advocating the use of "hands-on" instruction. Towards enhancing accessibility to a wide demographic in a more cost-effective manner, web technologies provide a platform that is widely available for mass consumption. The development capitalises on the fact that the majority of UK households have access to technologies, such as web-based tools and mobile devices.

***Keywords*: haptics, virtual learning environment, experiential, exploratory, cultural heritage, serious games**

I. Introduction

Learning ancient history is traditionally dependent upon intangible narratives often accompanied by illustrations and historical facts. To promote better absorption of knowledge, complete involvement of learners in their learning process is essential. Experiential learning [1] advocates such engagement. In their model on exploratory learning, de Freitas and Neumann [2] expand the experiential model to include virtual environments.

However, virtualisation of the learning environment often implies experiences become abstract subsets of their real-world counterparts, and therefore fissures can emerge in the experiential model between action, (virtual) experience, and reflection. These often manifest themselves as unfulfilled learning outcomes due to inadequate fidelity, or reports of cognitive overload as learners struggle to address the additional demands required to reflect on virtual experiences in the context of real-world events [3][4][5]. Hence, it is essential to narrow the gap between virtual and real spaces, and thus enable experiential learning techniques to be more readily and effectively applied.

Within the domain of cultural heritage, ancient artefacts that are physically unavailable in a class-room setting may be made tangible in a virtual environment (VE). 'Seeing is believing' - but physically touching a virtual artefact may narrow the gap between what we perceive as a virtual and real object. The human sense of touch is an active, informative, and useful perceptual system to complement visual information [6].

The educational benefits of such an approach are well-documented; Shams and Seitz [7] advocate multisensory teaching approaches as mirroring more closely evolved learning processes, suggesting unisensory approaches are sub-optimal and that their selection is based in practicality rather than pedagogy. More recent work by Slater [8] has confirmed that increased visual realism leads to more realistic user response, and extending this realism to include other senses has strong potential to create a more effective learning environment.

Existing works exploring such an approach commonly employ specialist technologies, which can be expensive and are not easily available to a general audience. Hence, to promote engagement, the deployed technologies have to support accessibility to a wider demographic. The means of transfer thus require optimisation- simple, familiar, cost effective and easily available for mass consumption.

This article reports on the ongoing development of the Roma Nova project, built around the Rome Reborn Model [9]-[11], which provides a virtual reconstruction of the city of Ancient Rome within the Aurelian Walls. Towards providing a multisensory game-based learning platform for cultural heritage, the proof-of-concept applies a model for experiential and exploratory learning through the incorporation of tactile interfaces into a virtual environment using haptic technology. Accessibility to a wide demographic is achieved by capitalising on the fact that mobile technologies and web applications, coupled with graphical user interfaces and browsers, are common in education and at home [12][13], and an abstraction layer provided through middleware allows a wide range of haptic devices to be supported.

II. Related Work

In the domain of VEs, multimodal interfaces are increasingly being explored as tools for providing a more engaging learning experience. Research in human-computer interfaces aims to correlate the natural interfaces between human subjects with their surroundings, and to constitute their characteristics in a VE, with benefits for both usability and immersion.

VEs have previously been employed within the domain of cultural heritage. Applications, such as Virtual Egyptian Temple [14] and Virtual Gettysburg [15] present users with virtual recreations of ancient artefacts, allowing them to manipulate these objects in three dimensions. Large-scale events such as battles can also be recreated in a virtual environment, allowing users to move around freely and observe events from any angle or location. ‘First-hand’ experience or “hands-on” instruction, in this case direct ‘contact’ with tactile feedback, is however not advocated by these environments.

There is evidence that multimodal interfaces can create more immersive experience [16].Sound and sight may be the easiest senses to manipulate using conventional interaction techniques, but they are not the only senses. Haptic technology, being the latest innovation in interactive devices, is designed to communicate through the subtle and sensitive channels of touch and it has the potential to enrich experience in learning. The ‘feel and do’ approach of exploratory learning is highly encouraged by this form of interactivity that promotes ‘first-hand’ experience.

When haptic feedback is available during the exploration of three dimensional objects, studies have shown that individuals develop more three dimensional understandings than when only visual feedback is available (e.g., [17]-[19]). There is evidence that learners tend to explore a virtual object in a more natural manner, where haptic capability allows them to explore the visible and hidden parts of the object, whereas the exploration of only the visible part is preferred in a visual only environment [18]. Studies by Jones et al. [19] supports such findings showing that using a point probe haptic interface as a tool to explore virtual objects tends to support the development of three dimensional understandings of the objects. Morris et al. [20] suggested that in conjunction with visual feedback, haptic perception in a virtual training environment may enhance the teaching of sensorimotor skills that have a force-sensitive component to them, such as surgery.

Most of the existing applications have focused on using haptic to simulate real world situations for training purposes ranging from surgery to military. However, recent advances in technology now allow us to add haptic feedback to a wide range of software applications.

Naturally, the stimulation of tactile perception is very useful in cultural applications, where ancient artefacts are mostly beyond reach in a physical world [21]-[23]. A collection of cultural heritage institutions have already embraced haptic technology, for instance, The Museum of Pure Form [24] allows visitors to interact with three dimensional art forms and explore the museum via stereo vision and experience tactile interaction with virtual sculptures. The Interactive Art Museum [23] provides the ability to touch rare art pieces. Figueora et al. [25] demonstrated a similar multimodal platform based on the Gold Museum in Bogota, where commercial devices were integrated in order to allow visitors to see in stereo, hear, and touch replicas of small objects. The visually impaired may also be empowered, where sight is no longer the only necessary sensory means to appreciate artwork or a virtual space in general [12]. Touch becomes an efficient instrument for attaining information when vision alone is inadequate or impossible [6].

Such applications however deploy technologies, which are audience and location specific due to their sophistication, complexity and cost. Figueora et al. [25] confirmed the interest of using this technology in real-world setups, although there are deployment and usability issues with regards to the general public. Hence, to reach a wider demographic, a more accessible media is crucial. Web and mobile platforms are common assets of most households in Britain and may allow beneficiaries in dispersed locations to be supported. For instance, some 73 per cent of UK households have Internet access in 2010 [26].

Modern cultural heritage exhibitions have evolved from static exhibitions to dynamic and challenging multimedia explorations [27]. The main factor for this has been the domination of the web technologies, which allows cultural heritage institutions and other heritage exhibitions to be presented and promoted online. VEs for cultural heritage can offer much more than what many current cultural heritage institution web sites offer, i.e. a catalogue of pictures and text in a web browser. White et al. [27] introduced a new level of multimodal experience by implementing an augmented-reality platform for cultural heritage on a web. This platform allows users to not only view and interact with web-based cultural artefacts but to also experience a mixed reality visualisation of the artefacts. By using special markers, a webcam and possibly a mixed-reality eyewear, virtual artefacts can be viewed in a real-environment.

To support tactile perception on a web platform, the existing human computer interface has to be extended with haptic capability. Applications such as The Hanoi Game and Pool Game implement a simple haptic interface over the web, which demonstrates the possibility of encouraging a “first-hand” learning experience when compared to a more encyclopaedic approach [28]. Yu et al. [29] experimented on a web-based application for blind users by using a force feedback mouse. There is a great potential in deploying such an innovative technique in a multimodal framework.

III. Multisensory Framework

Under an experiential model of learning, individuals are encouraged to reflect on their actions and consequences to foster understanding, and reapply this understanding to future actions. In proposing the experiential model, Kolb [1] put forth a refined definition of learning as “the process whereby knowledge is created through the transformation of experience”. From this learning experience, the outcomes are Concrete Experience (feeling), Reflective Observation (watching), Abstract Conceptualization (thinking) and Active Experimentation (doing). Yet when transposed into a virtual learning environment, the experiential model must address the need for reflection to encompass the translation between virtual action and real understanding. The more effectively the virtual world is able to recreate the real, both in terms of fidelity and multimodality, the less scaffolding is required to support this translation.

In support for such pedagogic perspectives, we have developed a multimodal framework that will bring Brain Computer Interaction (BCI), sound and haptic interaction together into the Roma Nova project which is targeted at children (11-14 years old) to teach cross-disciplinary approaches to curriculum-based education.

The Roma Nova project is built around the Rome Reborn Project - the most accurate reconstruction of ancient Rome currently in existence. The Rome Reborn model is a complete collection consists of a digital terrain map of the city, 7000 buildings and various ancient artefacts within the late-antique Aurelian Walls, which were reconstructed based on reliable archaeological evidence [10][11][30] (see figure 1).

Figure 1. The Rome Reborn project [30] is a 3D model reconstruction of the A.D. 320 city of Rome

A diagram that illustrates interaction and visualization technologies employed in the multimodal platform is presented in figure 2.

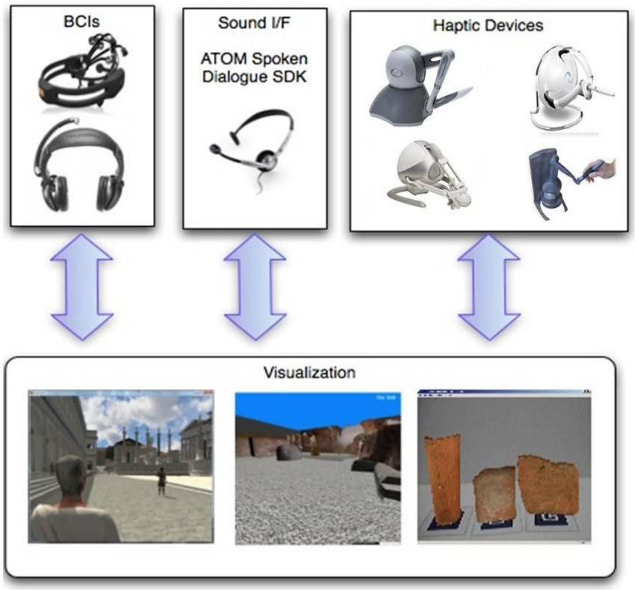


Figure 2. Multisensory framework to support various modes of interface, such as the brain computer interface (BCI), spoken dialogues and haptic interfaces

The system is composed by three layers:

- The Interaction layer supports various interaction modes that can be grouped into three categories: BCI interaction, Natural Speech Interaction and interaction with haptic devices.
- The Middleware Communication layer (MCL), an interactive framework supports data sharing between distinct sets of devices.
- The Visualization layer supports different game and visualization engines such as Unity, H3D/X3D and TV3D.

Reflective observation paired with abstract conceptualization is not only uncommon in a typical classroom setting and encyclopaedic learning but also in a virtual learning environment. As an attempt to address the need to emphasise on the importance of concrete experience via active experimentation, stimulating tactile perception may enhance not only engagement with the learning process but also the understanding of experiment subjects/samples.

This approach complements or perhaps enhances conceptualization and observation by placing a high emphasis on transforming the lesson-learned to real applications and implications as well as analysis-oriented and hands-on skills. Therefore, "physically" touching a virtual artefact may narrow the gap between what we perceive as a virtual and real object. Towards achieving an engaging environment on a more familiar and cost-effective platform within the context of cultural heritage, the two important parameters are the incorporation of tactile perception in a virtual environment in tandem with the experiential learning technique and the need to promote accessibility by employing a browser-based platform, off-the-shelf haptic technology and open-source software.

In order to incorporate both tactile perception and visual elements within a VE, H3D by SenseGraphics provides an open source haptic software development platform (H3D API) that uses the open standards OpenGL and X3D with haptic in one unified scene graph. H3D API supports a rapid development process and cross platform implementation, which makes it feasible for web applications. Haptic devices supported include Phantom Desktop, Phantom Omni and Novint Falcon., H3DAPI is designed chiefly to.

To promote cost-effectiveness and therefore increase accessibility, an off-the-shelf Novint Falcon is employed due to its affordability, usability and stability within the domain of games. It is also supported by H3D and does not require prior technical skills and experience.

To enrich users' experience in a virtual world, not only does the Novint Falcon (figure 3 (a)) support virtual navigation in a three dimensional space, it also allows users to experience high-fidelity three-dimensional force feedback that represent texture, shape, weight, dimension, or/and dynamics upon interaction with virtual artefacts (figure 3 (b)).

(a) (b)

Figure 3. (a) The Novint Falcon and the (b) interaction with an artefact.

The following sections describe the scene development that is built on top of the H3D API and web deployment enabled by a plug-in for haptics on an internet browser.

IV. Scene Development

A virtual scene with haptic capability can be developed using H3D, which is based on X3D (the Extensible 3D file format) - an ISO open standard scene-graph design that is easily extended to offer new functionality in a modular way. It employs a structural division in the scene-graph concept - the use of Nodes and Fields. Nodes and field are used to define geometries, physical attributes and behaviours that make up the artefacts and the surrounding environment within the virtual space.

For instance, the following X3D scene graph defines a simple scene displaying a red sphere.

```
<X3D profile='Immersive' version='3.0'>
 <Scene>
  <Group>
   <Viewpoint position="0 0 0.6"/>
        <Shape>
          <Appearance>
            <Material diffuseColor="1 0 0"/>
        </Appearance>
        <Sphere radius="0.05"/>
      </Shape>
  </Group>
 </Scene>
</X3D>
```

To support real-time interactivity and behaviours, there are three levels of programming for H3D - using C++, X3D or Python. X3D and Python are high level interfaces to the API, which allows the definition of dynamic behaviour upon real-time interaction with virtual objects. Application or user-interface behaviour is described using Python. For instance, the deformable behaviour of a soft object can be rendered as a response to tactile interaction. C++ provides an access to the API, where new nodes and fields can be created dependent upon the requirement of the virtual world development and the desired virtual behaviour.

A. Visualization

Selected digital models from the collection of artefacts of the Rome Reborn model were used to develop a virtual scene as a basis for the visualisation of the ancient world. A screen shot of a third-person view of a scene in ancient Rome is shown in figure 4. Such digital assets complement the resources required to teach ancient history and cultural heritage within this era.

To create a virtual scene made up of ancient artefacts and architectures, geometries from these assets, mainly in a 3D Studio Max (3DS) format, were repurposed and translated into X3D to provide the corresponding visual scene-graph, which were next extended with haptic functionality

Figure 4. A player's view in a role-play game set in a scene based on the Rome Reborn model

Figure 5 illustrates the general development process from the original model to the equivalent X3D scene-graph with haptic definition. The conversion process produces X3D scene graphs from the selected models.

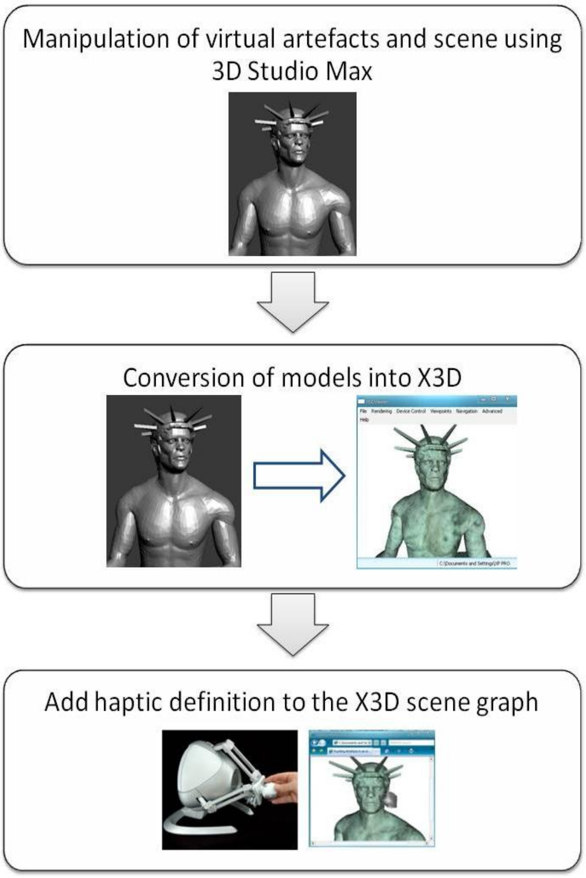


Figure 5. An overview of the scene development flow

The following scene graph illustrates a modular representation of an artefact in X3D without haptic definition. Different parts of the artefact are scripted in separate groups.

```
<X3D profile='Immersive' version='3.0'>
<Scene>
<Group DEF = "Statue">
   <Group DEF="Platform">
   <Shape>
            <Appearance>
              <ImageTexture url='tex.JPG'/>
```

```
        <Material
          ambientIntensity='0.2'
          diffuseColor='1.0 1.0 0'
          emissiveColor='0 0 0'
          shininess='0.2'
          specularColor='0 0 0'
          transparency='0'/>
      </Appearance>
      <IndexedFaceSet
        coordIndex="0 1 2 3 -1…”
        normalIndex="0 1 2 3 -1…”
        texCoordIndex="0 1 2 3 -1...”>
        <Coordinate point="1920.02 – 1326.73 -
          1724.6, …”>
        <Normal vector="0 1 0,…”
        <TextureCoordinate point="1 0, 0.8 0,…”>
      </IndexedFaceSet>
    </Shape>
  </Group>

  <Group DEF="Artefact_body">
    <Shape>
      <Appearance>
       ...
      </Appearance>
      <IndexedFaceSet
      ...
      </IndexedFaceSet>
    </Shape>
  </Group>
  ...
</Group>
</Scene>
</X3D>
```

The drawback of such development approach is the actual Rome Reborn model comprises of complex geometries, which require high conversion time into equivalent X3D scene graphs. Therefore, the level of details of the geometries has been reduced, especially for background artefacts.

A huge number of artefacts in a scene will demand a huge portion of development time if haptic/tactile properties are to be defined for every single artefact. However, in tandem with the aims of experiential and exploratory learning methods, it is more practical to assume that a user/player/learner will only closely examine a selected number of artefacts relevant to the learning objectives.

B. *Haptic Definition*

Tactile interaction with objects in a virtual space promotes multisensory learning experience absent from a normal class-room setting. Tactile feedback respective of the texture, shape and material of the artefacts upon interaction will enrich learners' experience through such an exploratory engagement.

H3D comes with a full XML parser for loading scene-graph definitions of X3D extended with haptic functionality. With the haptic extensions to X3D via H3D API, tactile definition can be incorporated into the scene-graph.

Hence, surface properties have to be defined in order to be able to touch an artefact, in this case an X3D shape. H3DApi supports different types of surface properties [31], such as:

- SmoothSurface - a smooth surface without any friction
- FrictionalSurface - a surface with friction, which can either be static or dynamic
- MagneticSurface – a surface with magnetic behaviour
- OpenHapticsSurface – properties associated with a specific renderer
- DepthMapSurface - a surface with friction influenced by a texture map that defines how deep the surface feels
- HapticTexturesSurface - a surface with friction influenced by the texture definition, where the shape is touched and how the texture coordinates are specified for the shape.

As an example, the artefact (marble statue) was assumed to be solid and the surface was considered as with friction. Based on the scene graph in section 4.1, haptic definition was included under the Appearance node, as shown below:

```
...
<Appearance>
  <FrictionalSurface
   stiffness='1'
   staticFriction = '0.5'
   dynamicFriction='0.4' />
...
</Appearance>
...
```

The stiffness values (0 to 1) represent soft to solid and the static friction denotes the amount of resistance to the movement of the cursor when it is touching the surface. The resistance to dynamic movement is denoted by the dynamic friction value.

In the virtual environment, haptic navigation and interaction with the artefacts is achieved by using a three dimensional cursor in the shape of a hand (see figure 6). This cursor was defined in the main X3D scene containing the definitions of the artefacts and the surrounding objects. Using such cursor promotes a more oriented navigation in three dimensional spaces compared to the default cursor in the shape of a sphere.

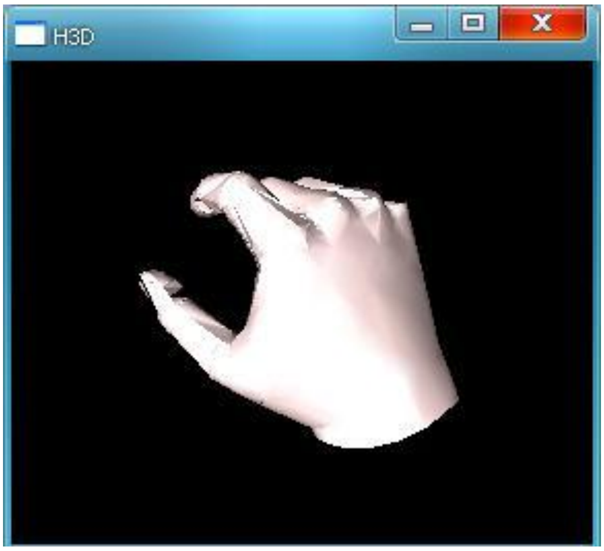


Figure 6. A 3-Dimensional Haptic cursor

Figure 7 illustrates real-time rendering of the haptic cursor that represents tactile interaction with a solid artefact as well as navigation within the virtual scene.

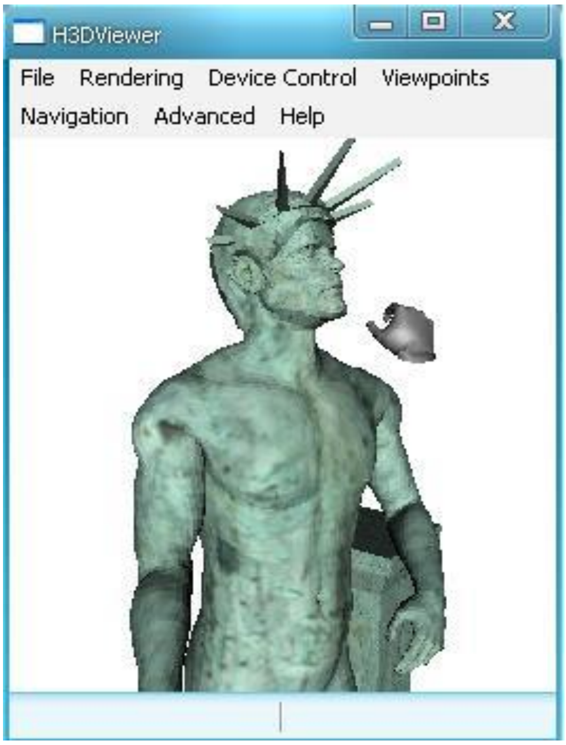


Figure 7. The artefact and a haptic cursor.

C. *Web Deployment*

In H3D, a pre-defined Python scripting can be used to express more behaviour in the scene, such as a deformable behaviour upon interaction. Figure 8 demonstrate haptic interaction with a non-solid surface and the corresponding visual response.

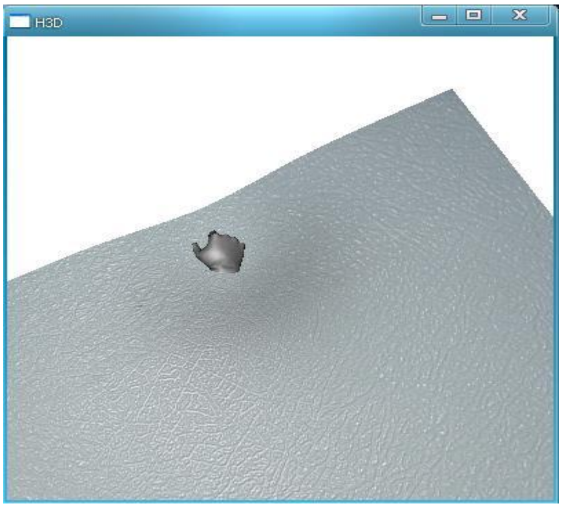


Figure 8. Haptic interaction (hand cursor) with a soft artefact

The scene-graph definition of the virtual environment was embedded within an HTML script, which can now be rendered on a web browser via the H3D-Web plug-in. Figure 9 illustrates the general architecture implemented to support the deployment of a haptic-enabled scene developed using H3D API on a web-browser .

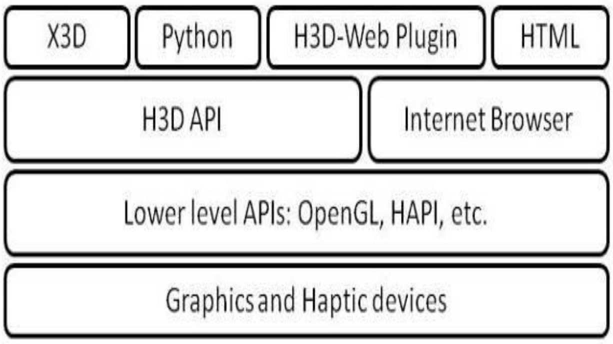
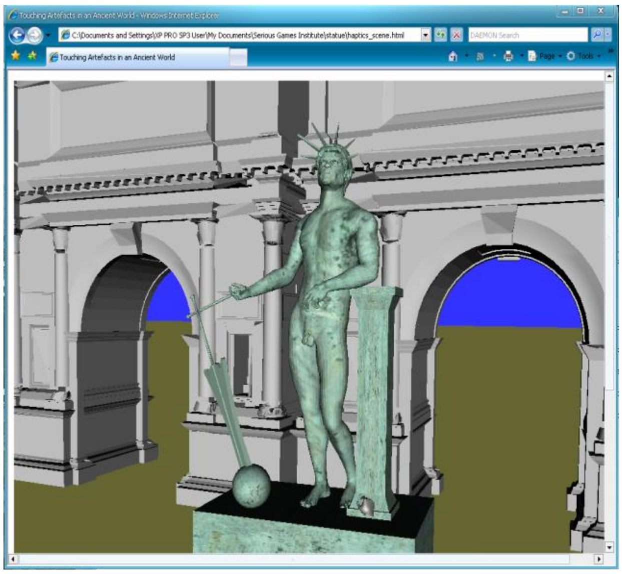


Figure 9. Architecture of a haptic-enabled browser

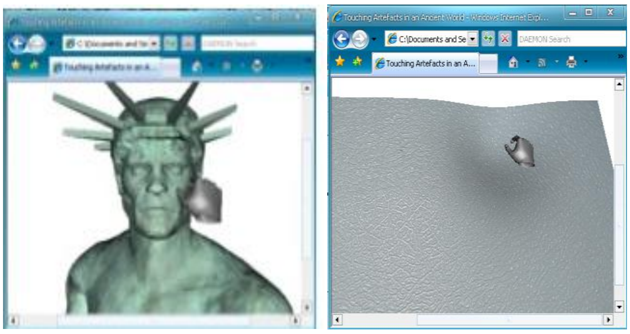
By embedding the X3D scene graph within the HTML (see the following script), a web page can be extended with haptic capability.

```
<html>
 <head>
  <title>Touching Artefacts in an Ancient World </title>
 </head>
 <body>
     <embed type="model/x3d+vrml"
            width="1000" height="800"
            src="rome_scene.x3d">
     </embed>
   </body>
</html>
```

Figure 10 illustrates a haptic-enabled browser, where learners can experience tactile feedback from real-time interactions with ancient artefacts over the web using a Novint Falcon device. To optimise the learning environment, the platform architecture may be set up on the client's machine as a downloadable installer that encapsulates the required components. The runtime processing, such as rendering, could thus be delegated to the client. The web content including the haptic-enabled visualisation may reside at the server side.



(a)



(b) (c)

Figure 10. (a) An ancient world [33] rendered on the haptic-enabled web browser that supports tactile interaction with (b) solid and (c) soft artefacts.

V. Conclusions

By employing both visual and tactile perceptions in a virtual learning environment, a first-hand learning experience may be achieved. This paper has briefly described an innovative approach in introducing tactile perception in learning over the web, which aims to reach a wider demography than museum-based haptics in a cost-effective way. This development complements the existing project on cultural heritage as part of the Roma Nova project at the Serious Games Institute.

Several limitations exist with the current framework. Firstly, the scene development is dictated by the complexity of the Rome Reborn model, which influences the amount of time required to define haptic properties for the artefacts within the scene. Automating this process to define haptic properties can to an extent be performed by analysing the material properties conventionally used to set texture and lighting behaviour; however, as these are not typically defined with haptic interaction in mind, full automation would require advances in standards for how virtual objects are represented. Further work will include identifying the relevant artefacts that will enrich learner's experience within the virtual ancient world through evaluations in schools. This implies that only a selected number of artefacts will provide any tactile feedbacks upon interaction. Secondly, challenges exist in providing high levels of realism, in terms of both visual and tactile fidelity, for deformable objects. Existing work (e.g. [32]) can be adopted to address these concerns through an increase in realism and accuracy in object behaviour for the surface geometries of the artefacts. Thirdly, there are also possible latency and bandwidth issues when attempting to provide real-time high quality graphics to non-broadband users; however, this can be addressed by providing an option to download virtual scenes for local interaction.

Other further work will include extending the existing multimodal game-based learning framework developed at the Serious Games Institute with the haptic-enabled web environment. The evaluation of the level of engagement, motivation and cognitive benefit of the proposed learning platform will also be explored in the future.

By making available a whole new category of sensations on a web platform, haptic technology will open up significant possibilities for developers and learners alike. The framework can be further adopted and extended by other developers of virtual cultural heritage, game-based learning, healthcare technologies, commercial applications within the context of business-to-business (B2B) and business-to-customer (B2C) scenarios as well as management or training of adaptive robotics applications [34] based on similar pedagogy.

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