

Declarative Integration of Interactive 3D Graphics into the World-Wide Web: Principles, Current Approaches, and Research Agenda

Abstract

With the advent of WebGL, plugin-free hardware-accelerated interactive 3D graphics has finally arrived in all major Web browsers. WebGL is an imperative solution that is tied to the functionality of rasterization APIs. Consequently, its usage requires a deeper understanding of the rasterization pipeline. In contrast to this stands a declarative approach with an abstract description of the 3D scene. We strongly believe that such approach is more suitable for the integration of 3D into HTML5 and related Web technologies, as those concepts are well-known by millions of Web developers and therefore crucial for the fast adoption of 3D on the Web. Hence, in this paper we explore the options for new declarative ways of incorporating 3D graphics directly into HTML to enable its use on any Web page. We present declarative 3D principles that guide the work of the *Declarative 3D for the Web Architecture W3C Community Group* and describe the current state of the fundamentals to this initiative. Finally, we draw an agenda for the next development stages of Declarative 3D for the Web.

CR Categories: I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Virtual Reality I.3.6 [Methodology and Techniques]: Standards—Languages

Keywords: Declarative 3D, HTML5, DOM Integration, Polyfill

1 Introduction

The Web evolved from a text-based system to the current rich and interactive medium that supports images, 2D graphics, audio and video. These types of new media have made the Web experience richer, more attractive to users, etc., than ever before, and opened up possibilities for new types of applications and usage. The major media type that is still missing is 3D: synthetic, possibly photorealistic images in 3D with animation, as smoothly integrated in the everyday Web experience as images or video. Just as the appearance of images or video could open new application possibilities, access to the 3D on a Web site would make it possible to include realistic models of 3D objects – from models of buildings to representation of the human body or the sceneries for computer games. With WebGL [Marrin 2012], a JavaScript binding for OpenGL ES 2.0, this seems feasible; however, the goal would be to achieve the same smooth inclusion of 3D content in a Web page like we experience today with images or SVG-based 2D graphics.

Although some of these goals could also be achieved by imperative means (e.g., through the usage of WebGL), developments of 3D models have a long tradition of using declarative approaches, which is also in line with some of the fundamental principles of Web development. It is therefore important to explore how the experiences accumulated in two different communities, namely the Web Development and Computer Graphics communities, can be capitalized upon to achieve the long term goal of using 3D on the Web the same way as we do with 2D graphics and video today. Moreover, while imperative graphics APIs are powerful and necessary, a *Declarative 3D* approach can provide web authors an easy way to add interactive high-level declarative 3D objects through the

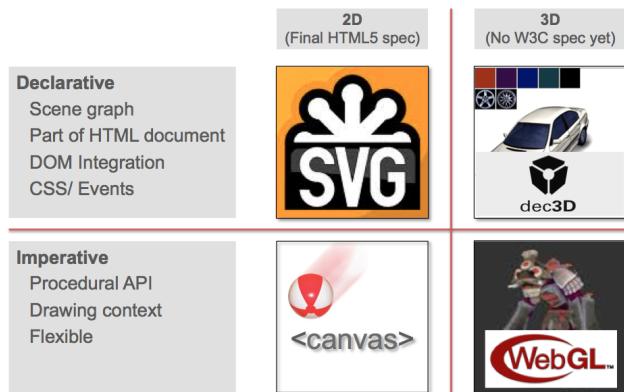


Figure 1: The position of the Declarative 3D approach in the current Web graphics technology ecosystem.

HTML Document Object Model (DOM) allowing them to easily create, modify, share, and experience interactive 3D graphics using HTML documents. Figure 1 depicts the position of the Declarative 3D approach in the current Web graphics technology ecosystem.

It is arguable that the emerging support for an imperative 3D API for the Web is useful but insufficient for broad acceptance and usage of 3D on the Web. A declarative approach that offers qualified concepts and that is tightly integrated with current web technologies, such as JSON or XML for scene construction, DOM for scene manipulation, and CSS for styling, is necessary to support a fast adoption and broad use of interactive 3D graphics by the millions of Web developers. The provided concepts must lift the hardware-oriented imperative application programming interfaces to an expressive and more easily usable level. Therefore not the low-level data structures of existing GPU layers must be in the center of the design but high-level elements and items like 3D objects, transformations, material descriptions, and lights. Instead of teaching Web developers 3D graphics APIs, the goal is to bring 3D graphics to the point where it is natural for Web developers to just make use of it. While this might not be possible for every possible use of a low-level API, it still can cover the vast majority of use cases.

The *Declarative 3D for the Web Architecture W3C Community Group* (Dec3D) [W3C Community Group 2013] was thus founded to suggest and create methods to add high-level declarative 3D objects to the HTML DOM [W3C 2005], so users can share and experience interactive 3D contents. Moreover, this not only allows creating new content from existing content but also to index and search 3D content. The core mission is to determine the requirements, options, and use cases for the integration of interactive 3D graphics into the Web technology stack in a declarative way, which hopefully will provide a foundation for future standardization. Therefore, the group aims at presenting common use cases that define how 3D might intersect and interact with HTML5, DOM events, CSS, SVG, GeoLocation, Augmented Reality, Efficient XML Interchange (EXI) [W3C 2011] and other key working groups, whereas certain complex data types (e.g., transformation matrices) and computations are also of mutual interest. In this regard, this paper presents the current state and efforts concerning Dec3D.

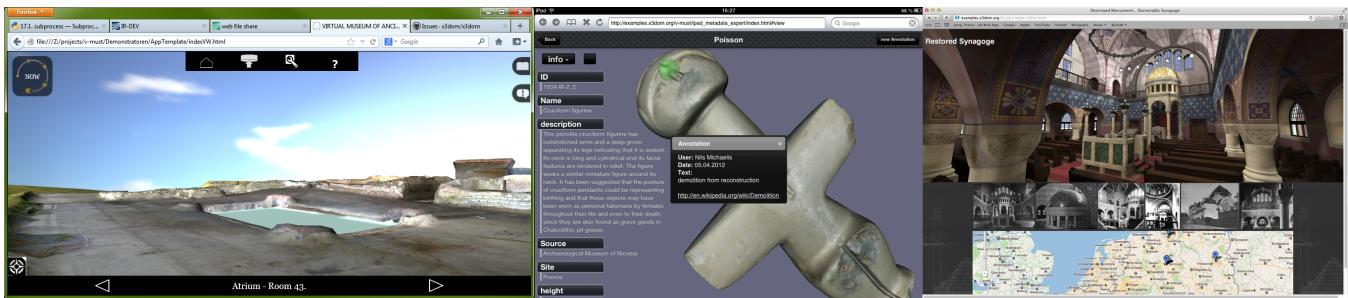


Figure 2: From left to right: walkthrough of Roman heritage site; cultural heritage object explorer with metadata; restored virtual synagogue.

2 Declarative 3D Principles

Here we describe declarative 3D principles, where the following goals should guide the development of DOM-based 3D graphics.

Following the Established Principles of the Web Declarative 3D is being developed to significantly lower the barrier for authoring 3D content for Web sites by duplicating the key features that enabled the growth of the early Web and its further success.

Separation of structure from content Underlying the Web from its earliest days was the separation of structure from content. The concept of a paragraph specified by the `<p>` tag was separate from its content. Declarative 3D is attempting to bring the same separation to 3D graphics inside of web pages. The concepts such as definitions of 3D objects, transformations, materials, etc. should be implemented in a declarative 3D description as an extension to HTML5 [Hickson 2012] using any existing or future extension mechanism.

Separation of content from style One of the principles of the current Web is also the separation of content and style, most notably through CSS. The successful integration of SVG [W3C 2012b] with HTML was made much easier due to the fact that SVG was already following this principle. The objective here is to extend the use of CSS for styling 3D graphics. One example can be the use of the latest CSS3 3D Transforms [W3C 2012a] to allow manipulating not only 2D but also 3D objects.

Use of the Document Object Model The DOM [W3C 2005] is a platform- and language-neutral interface that allows programs and scripts to dynamically access and update the content, structure and style of Web documents. Declarative 3D should use the DOM API to examine and modify elements on the 3D scene and their attributes by simply reading and setting their properties. As the DOM provides access to user actions (e.g., pressing a key or clicking a mouse button), it should also be used as a main interface to interact with 3D contents.

Embedded 3D graphics should reuse existing W3C techniques, specifically from HTML5 and SVG, as far as possible and propose extensions only where specific features are necessary or provide significant benefits. Where new concepts are introduced their relation to and effects on existing Web standards should be analyzed, evaluated, and discussed with the respective W3C working groups.

3D Content Creation and Reuse While the creation of original 3D geometry and appearances still requires 3D specific know-how, the reuse, configuration, and manipulation of such content should be made similarly easy as for 2D Web content now. The solution should hide internal data structures and algorithms and provide users convenient ways to edit and manipulate such scenes. A key success factor for Declarative 3D on the Web will be the ability to

generate new or reuse existing content. This requires that suitable exporters and converters can be built. However, as 3D on the Web is supposed mainly as a delivery mechanism, it is not necessary to include the ability to semantically represent all 3D features.

Platform Independence 3D content needs to be described in a way that does not rely on a specific render API such as OpenGL or DirectX nor on a specific rendering technique such as rasterization or ray tracing only [Rubinstein et al. 2009; Schwenk et al. 2012]. This should allow for content to be portable across browsers, rendering techniques, and hardware platforms, while taking advantage of available features wherever possible. The results of rendering content under such different environments should be highly predictable.

Efficiency and Scalability Interactive real-time 3D graphics enables new forms of interactivity on the Web but also adds significant new requirements on user agents. A key requirement for the selected technology therefore is the possibility to implement it efficiently (cf. e.g. [Trevett 2012]). Native implementations allow utilizing all (battery) resources more efficiently while leveraging heterogeneous hardware. Thereby, the CPU time can be used for the application instead for rendering, collision, scene-housekeeping, etc., which is esp. critical for mobile devices. Since 3D scenes can become rather large, any solution should target scalability in the sense that 3D content should run across different platforms (from mobile devices to high-end graphics hardware) with predictable performance. Mechanisms should be in place to handle cases where the performance provided by a user agent on some platform is not sufficient, e.g. by allowing for switching to different content (e.g. lower LOD) or provide alternate methods of delivering the content (e.g. server-based rendering delivered via streaming video).

Security and Digital Rights Management Secure delivery of Web content is a general problem and not specific to 3D data. However, the economic value of 3D data might make the problem more acute. Any proposed solution should therefore be based on a general approach to secure Web content. However, we first need to collect use cases, extract requirements and examine how far existing methods (e.g. [Koller and Levoy 2005]) and standards can be transferred to the proposed architecture. It is already demonstrated that the application of XML Encryption and Signature is needed for document fragments as well as full documents, since high-fidelity or sensitive portions of 3D models often need special protections.

Accessibility and Usability Accessibility improvements serve all users, not just people with disabilities. A problematic aspect of many 3D graphics approaches however is that user navigation and interaction is implemented inconsistently. Therefore, users familiar with one approach are impeded when navigating or interacting with

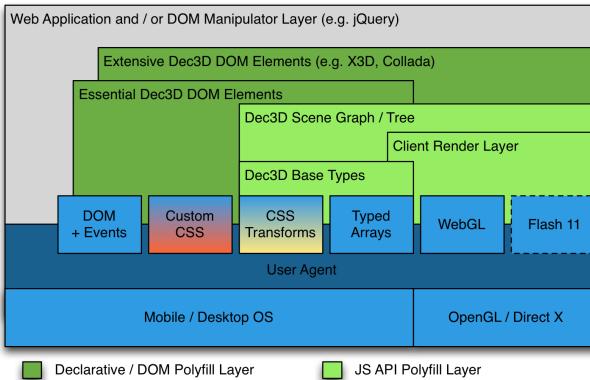


Figure 3: Proposed declarative 3D “polyfill” runtime architecture.

other 3D scenes and models. Examination of relevant Web Accessibility Initiatives (WAI) principles might provide significant benefit. Conversely, use of declarative 3D graphics models might provide major benefits when describing the accessibility features and constraints of real-world objects and locations. Declarative 3D goals and potential solutions may achieve significant benefits if they are harmonizable with WAI imperatives.

Leveraging Web Development Infrastructure The Web has become the new application development platform for our time. Countless rich internet applications are being created at a dizzying pace. The “apps” world for mobile applications has also become a huge phenomenon. One important enabling technologies is JavaScript [Crockford 2008], which has evolved from a toy language into a robust and richly nuanced tool that is the basis for much of the recent explosion in Web applications. Declarative 3D, by living within the structure of Web apps is poised to leverage the huge collection of tools and infrastructure that already exists such as jQuery [Resig 2012] etc. The ability to take existing Web debuggers, editors, and viewers and use these tools to create, edit, and debug 3D content is a tremendous benefit and just begins to scratch the surface of development tools, created for Web application development, but which we can use for 3D content development.

3 Declarative 3D Frameworks

As already mentioned, the Dec3D Community Group [W3C Community Group 2013] has been formed to determine the requirements, options, and use cases for the declarative integration of interactive 3D graphics capabilities into the Web technology stack, which will provide a foundation for future standardization. While this standardization is our goal, we still need platforms allowing for the experimentation and for the assessment of our design decisions. We also need to reach out to Web developers who could provide us with valuable feedback as early as possible.

3.1 X3DOM and XML3D

With X3DOM [Behr et al. 2009] and XML3D [Sons et al. 2010] two open-source frameworks are available, which are briefly introduced in this section. Both frameworks support the ongoing discussion in the computer graphics and Web communities how an integration of HTML(5) and Declarative 3D content could look like. This discussion is followed by the presentation of the so-called “polyfill” approach for further development activities.



Figure 4: A highly dynamic declarative 3D scene with nine animated and skinned characters. The calculation is either performed with classical sequential JavaScript or in parallel exploiting Intel’s River Trail proposal for parallel data computations in JavaScript.

Fraunhofer IGD’s X3DOM [Behr et al. 2009; Behr et al. 2012b] is a JavaScript-based open-source framework for declarative 3D graphics in HTML5 that aims at extending the HTML DOM tree with declarative 3D objects while employing modern Web technologies like CSS3, Ajax, DOM scripting, as well as WebGL and – as fallback – Adobe’s Flash 11 with Stage 3D [Adobe 2013] for GPU-accelerated rendering. The proposed 3D elements are mostly based upon the open ISO standard X3D [Web3D Consortium 2011], though X3DOM introduces a special HTML profile that basically extends the X3D Interchange profile. Additionally, instead of implementing the somehow odd X3D pointing device sensor component, X3DOM simply uses, and appropriately extends, the HTML UI/Mouse events such that 3D pick events are likewise supported.

Furthermore, to overcome various problems that come along when embedding 3D mesh data, which typically consists of several megabytes of vertex attribute data, directly into the DOM tree, the developers are working on efficient 3D mesh encodings that allow separating the node structure from the raw vertex data [Behr et al. 2012b]. In this regard, Figures 2 and 5 show several X3DOM applications from the cultural heritage and engineering domain, where the ability to efficiently handle big 3D data sets is of high importance. Based on this work, 3D transmission formats are now also a major topic at the Khronos Group [Trevett 2012], where it is similarly argued that raw 3D data, just like image, video or audio data, needs to be externalized from the HTML document.

XML3D [Sons et al. 2010] is a collaboration of DFKI and Intel VCI. Similar to X3DOM, it employs CSS3, DOM scripting, DOM events, and WebGL. In contrast to X3DOM, XML3D is designed as a extension to HTML5 from scratch. It does not define a scene-graph but uses the DOM tree structure for parent child relations and second level references e.g via CSS to (re-)use resources such as geometry data, material descriptions or animation data. These resources are not necessarily in the same document, but can also come from external documents in various formats, e.g. as JSON files.

This generic and consistent handling of resources allows fine-granular composition of data sources. It can be combined with Xflow, a declarative data flow component [Klein et al. 2012] that allows for dynamic meshes, morphing, animation of shader parameters, image processing and AR. The data flow computation can be mapped to hardware, e.g. by composition of WebGL shaders or by exploiting available APIs such as Web Workers [World Wide Web Consortium 2012] or River Trail [Herhut et al. 2012]. Figure 4

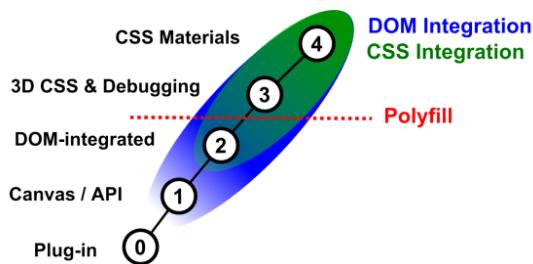


Figure 6: Levels of integration: current browser APIs only allow integrating with DOM and DOM Events, but not yet fully with CSS.

265 shows a XML3D scene with nine characters, skinned and animated
266 with Xflow.

267 3.2 Polyfill Approach

We also propose to measure a level of integration for 3D graphics in terms of W3C technologies (DOM, CSS, etc.) to explain existing and possible integration levels (Figure 6 shows that currently only level 2, DOM integration, is possible), and to finally identify a suitable integration level for declarative 3D. However, the latter imposes several problems in that it requires having a set of 3D-specific CSS properties or even a full shader description via CSS as well as a deeper integration into debugging tools like Chrome Developer Tools or Firebug. However, integration levels 3 and 4 are currently not yet achievable by a JavaScript implementation, because the required APIs are missing: it is not possible to introduce new CSS properties or to extend developer tools by an API.

It quickly became clear that a higher level of integration requires additional APIs in user agents. After discussions with browser vendors (namely Firefox and Chrome), who made it clear that integration of the desired extensions natively into their frameworks is not currently their priority, we decided to consider a polyfill approach for the further development activities. Nevertheless, communicating and requesting additional and missing features like custom CSS properties or CSS monitoring is necessary.

288 A *polyfill* is a downloadable piece of code, which provides facilities
289 that are not natively built-in to a Web browser [Sharp 2010]. For
290 example, many features of HTML5 are not supported by versions
291 of Internet Explorer older than version 8 or 9, but can be used by
292 web pages if those pages install a so-called polyfill. Polyfills can
293 also be used to add entirely new functionality to browsers.

294 Polyfill-based approaches allow deriving hard requirements for re-
295 lated and utilized W3C standards and user agent (UA) APIs imme-
296 diately. This leads to much more evolving concepts and solutions in
297 contrast to an overall declarative 3D specification. In the following
298 we hence list our most important UA requirements.

DOM The polyfill layer must be able to access and monitor changes in related DOM elements. This can be achieved using the now deprecated DOM Mutation Events as well as the new *MutationObserver*¹ objects.

Events The UA must support registration, firing, and extending UI events. This is mainly done through dynamic property changes in the JavaScript object, which currently represent the event for performance reasons.

Custom CSS properties The goal is to support scene management through custom CSS properties. Unfortunately, this was

not possible in the last years, but may change with the new CSS Custom Properties specification [W3C 2013].

CSS 3D Transforms The CSS 3D Transforms module [W3C 2012a] is now supported in all major browsers, but the methods to monitor final matrix changes are limited right now and should be further extended for optimal performance.

TypedArrays TypedArrays [Khronos 2012] were first introduced with the WebGL specification but are now an established method to process large portions of typed data efficiently.

Generic GPU access For client-side rendering the polyfill layer has to access the GPU functionality almost directly. Here, WebGL is there a perfect candidate and Flash 11/Stage3D a second fallback option.

To sum up, the X3DOM and XML3D experimental declarative 3D Web publishing frameworks are designed to explore different options for adding 3D graphics to HTML. Here, Figure 3 depicts our proposed declarative 3D polyfill runtime architecture, though we'd like to stress that the whole integration model is still evolving and open for discussion.

3.3 Declarative 3D Essentials

In this section we briefly outline our proposed essential elements for an upcoming Dec3D standard. First of all, a start element allows the transition from the HTML flow layout to 3D transformations:

```
<div>
  <dec3d style="border: 1px solid black;">
    ...
  </dec3d>
</div>
```

The DOM integration obviously extends the HTML hierarchy. But this comes along with certain issues like the correct treatment of CSS inheritance. Therefore, CSS integration is another point in that existing CSS properties should be used where applicable. Transformations for instance can be represented using CSS 3D Transforms [W3C 2012a]. In addition, a set of 3D-specific CSS properties (e.g. for defining the appearance) needs to be defined. However, custom CSS properties are not yet supported by any Web Browser, though finally this seems to change now [W3C 2013].

Moreover, not only standard DOM UI Events like ‘mouseover’ and ‘click’ shall be supported, but also events that contain 3D-specific context information. In this regard, the Browser API should expose convenience functions and special Dec3D base types consisting of a lean set of complex data types for 2D/3D graphics. Similarly, generic mesh data containers should be based on TypedArrays [Khronos 2012] with appropriate interfaces to efficiently modify the data, where external binary containers are used as transmission format [Behr et al. 2012b; Trevett 2012]. Thus, 3D geometry definition will stay close to OpenGL primitives.

Besides this, we further distinguish between essential Dec3D DOM Elements, where the focus lies on a minimalistic element set, as well as more comprehensive Dec3D DOM Elements (see middle of Figure 3), which build on top of those with the focus on usability and which for convenience could build on existing scene-graph standards like X3D [Web3D Consortium 2011].

Essential DOM elements are a basic set of built-in shaders, which should be enough for most use cases. Advantages are that they do not entail timing attack issues and that they can adapt to any target device. As textures, HTML elements like ``, `<video>`, `<canvas>` shall be used, whereas elements like `<svg>` and `<html>` can serve as interactive textures.

¹<https://dvcs.w3.org/hg/domcore/raw-file/tip/Overview.html#mutation-observers>

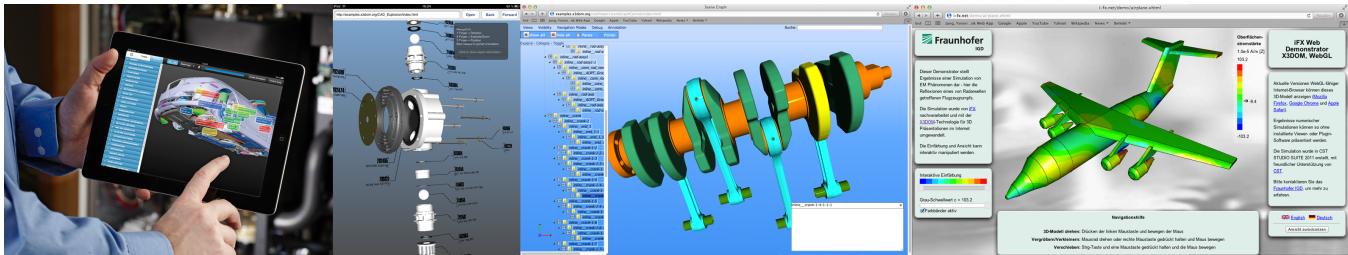


Figure 5: From left to right: web-based design review application with annotation markers; interactive explosion of CAD model on iPad; lightweight web-based viewer for 3D CAD data; visualization and interactive exploration of simulation data by using extended mouse events.

368 Lights are basically also shader parameters in OpenGL/WebGL
 369 [Marrin 2012], but here shall be represented as own elements to
 370 provide intuitive ways to define lights and to not obstruct more ad-
 371 vanced future concepts. Likewise, viewpoints can serve as link to
 372 certain points of interest within the document. However, it is still
 373 discussable if some pre-defined camera navigation modes should be
 374 part of the essential profile.

412 **capabilities of Dec3D.** For example, one application could require
 413 huge 3D datasets which are impractical for inclusion directly into
 414 the DOM; another could require real-time control of an external
 415 system (inter-process communication); another could integrate with
 416 a complex data base; another an illustration of complex data (infor-
 417 mation visualization) without a physical analog, and another a more
 418 traditional scientific visualization. Key to selection of these applica-
 419 tions is the use and demonstration of a declarative 3D requirement.

375 4 Declarative 3D Agenda

376 In this section we shape the agenda and identify upcoming research
 377 issues for the next development stage of Dec3D. During the 1st Intl.
 378 Workshop on Declarative 3D [Behr et al. 2012a] as well as during
 379 more informal meetings at Web3D and SIGGRAPH in 2011/2012,
 380 the members and supporters of the Declarative 3D W3C Commu-
 381 nity Group agreed upon the following topics to make the effort suc-
 382 cessful and for the W3C to adopt/develop a Dec3D standard.

420 **W3C Working Group Proposal** Finally, the Community Group
 421 should deliver reports documenting its progress, any conclusions
 422 it arrived at with respect to the standardization of *Declarative 3D*
 423 for the Web and, if reaching a positive conclusion, recommending
 424 a standardization approach as a basis for a future W3C working
 425 group on the same topic.

426 5 Conclusions

383 **Encourage Participation** All relevant stakeholders, e.g. devel-
 384 opers, designers, researchers, 3D artists, industry professionals,
 385 representatives of standards organizations, accessibility experts,
 386 and user-agent implementers, are encouraged to participate in this
 387 group. Participants should be willing to actively develop and do-
 388 nate materials towards the group's deliverables, as well as attend
 389 the group's teleconferences and face-to-face meetings.

427 While WebGL, a 3D imperative graphics API in the Web context,
 428 is getting more and more traction, we are still missing an easy way
 429 to add interactive high-level declarative 3D objects to an HTML
 430 document to allow anyone to easily create, share, and experience
 431 interactive 3D graphics, with possibly wide ranging effects similar
 432 to those caused by the broad availability of video on the Web. The
 433 main motivation is thus to make it easy to add 3D to Web pages
 434 by bringing 3D to the Web developers and not vice versa. This
 435 can be achieved by fully integrating 3D content into HTML5 docu-
 436 ments, where interactive 3D graphics is a first class DOM objects.
 437 Moreover, by reusing existing Web technology wherever possible,
 438 no new concepts are added unless absolutely necessary.

390 **Clear Definition of Use Cases and Requirements** The group
 391 needs to agree on a collection of use cases, where embedding 3D
 392 data in HTML using a declarative approach provides significant
 393 benefit. Here, declarative approaches esp. seem relevant for the
 394 industry, since they tend to think in formats not in APIs. Each use
 395 case should explore how publishers and consumers benefit from
 396 Dec3D. From these use cases, the group needs to derive and pri-
 397 oritize the different required dimensions for the Dec3D technical
 398 specification [Jankowski 2012; Le Feuvre 2012].

439 Another objective of this position paper on Declarative 3D for the
 440 Web is to evaluate the options for a successful standardization of
 441 a declarative approach to interactive 3D graphics as part of HTML
 442 documents. The idea is to collect suitable use cases, derive require-
 443 ments from them, and then find the essential set of features and con-
 444 cepts that enables broad uptake by authors and users of interactive
 445 3D on the Web. We are absolutely aware that our goal is ambitious
 446 and it will take some time to implement these features. Therefore,
 447 we call for more participation from the Web3D and W3C commu-
 448 nities that we believe is crucial to achieve our common and ultimate
 449 goal: 3D for everyone and everywhere.

450 References

399 **Clear Technical Specification** The next step is the creation of
 400 the clear, detailed and extensible technical specification of the im-
 401 plementation concepts and features necessary to cover a majority
 402 of useful requirements. Measurable properties need to be defined
 403 to quantitatively and/or qualitatively evaluate the achieved solution,
 404 document the pros and cons of each, and demonstrate that, based on
 405 the above analysis, there is a good chance of success in creating a
 406 W3C standard for Declarative 3D for the Web.

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407 **Outreach and Exemplar Applications** The group needs to con-
 408 tinue its outreach activities through the high quality demonstra-
 409 tions of the Declarative 3D philosophy using the open-source
 410 frameworks X3DOM and XML3D. Therefore, several applications
 411 should be identified, each requiring and demonstrating different ca-

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