Making Terrain and Models Portable Using 3D GeoPDFs

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ABSTRACT

The simulation landscape of today is beset with a multitude of simulation systems and visual image generators, each requiring multiple, often proprietary, data formats along with stringent hardware requirements and a team of qualified technical personnel for proper utilization. Many of the next generation, streamlined gaming engines even require at least a high-performance PC for optimal operation. These strict infrastructure requirements can create burdensome barriers for users looking for rapid verification of elements such as the contents of a synthetic environment representation or the visual representation of a 3D entity model. Other limitations such as geographic proximity, unavailability of qualified technical manpower, and cybersecurity are very real issues faced by users when timely access to a simulation environment or model is required.

Through experience with limitations like these, the Synthetic Environment Core (SE Core) program has validated the need and developed the capability to export a system agnostic three-dimensional (3D) model format that is accessible to all simulation stakeholders regardless of technical competency or infrastructure availability. This capability relies upon the widely utilized and globally recognized open Portable Document Format standard, more commonly known as PDF. Much like its two-dimensional counterpart, a 3D PDF retains all the visual formatting and geospatial registered attribution of its original source, while allowing it to be commonly accessible by all users across the full spectrum of computing hardware and portable devices.

The objective of this paper is to present a methodology for the generation of these common 3D PDF documents utilizing both synthetic environment terrain and 3D model data. This paper will also highlight ongoing innovative use cases for this capability across the Department of Defense (DoD) Modeling and Simulation (M&S) domain from terrain or model validation to end user mission planning, as well as discuss implications to the wider M&S user community as a whole.

ABOUT THE AUTHORS

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PREFACE

To illustrate the true portability and commonality of 3D PDF documents, the authors have populated the original version of this manuscript with a fully usable 3D PDF in Figure 1. In the event that document formatting is lost or this manuscript is physically printed, the authors have made all of the 3D PDFs used in the illustrations available at http://www.vcom3d.com/tactical/synthetic-environment-core. Please note that this webpage runs a version of JavaScript and may have issues displaying properly on some U.S. Government computer systems.

INTRODUCTION

More than ever before, training managers and stakeholders have their choice of countless simulation hardware, software, and image generation (IG) systems when it comes to modeling and simulation applications. Just walking down a single aisle at any given modeling and simulation conference will yield numerous options. While this prosperous IG environment promotes healthy competition between vendors, it can also create complications for professionals looking to export and interchange data between stakeholders for verification and validation (V&V). These complications can include file format mismatch, and strict hardware and systems licensing restrictions. Other limitations such as geographic proximity of users and developers, unavailability of qualified technical manpower, and cybersecurity are very real issues faced by users when timely access to a simulation environment or model is required.

Through the implementation of proven commercial-of-the-shelf (COTS) technologies, the Synthetic Environment Core (SE Core) program has implemented methodology to share models and synthetic environment representations (i.e., terrain) amongst users and stakeholders through a common simulation-agnostic format: a Three-Dimensional Geospatial Portable Document Format or 3D GeoPDF. Although they are not a direct replacement for a true simulation system or IG, 3D GeoPDFs provide the capability for users to rapidly view and interact with synthetic environments and models as an innovative tool for V&V, mission planning, and situational awareness.

Background

The most basic definition of a 3D PDF is that it is a PDF that contains one of two formats of supported 3D data: (1) Product Representation Compact (PRC; Defined by ISO 14379) and (2) Universal 3D (U3D; Defined by ECMA 363). PRC is an accurate, highly compressible 3D data format optimized to store, load, and display various 3D data, metadata, assembly structure, graphics information and Product Manufacturing Information (PMI), while U3D is an extensible format for downstream 3D Computer-aided drafting (CAD) repurposing and visualization. A 3D PDF combines dynamic 3D data with metadata, text, and images within a single easily transported document. The resulting 3D PDF files are secure, compact, and easy to share. Furthermore, they are completely interactive and can be opened, annotated, measured, and manipulated utilizing Adobe® Reader® and other Adobe applications (3D PDF Consortium, 2016). The integration of geospatial metadata within the 3D PDF format results in a 3D GeoPDF.

In the Department of Defense (DoD), MIL-STD-31000A provides requirements for the deliverable data products associated with a technical data package (TDP) and its related TDP data management products (Department of Defense, 2013). The standard specifies the use of 3D PDF as one of the approved TDP formats (Parks & Wurst, 2014). Furthermore, 3D PDFs are an integral visualization component of the recently developed DoD concept of Model-Based Enterprise (MDE) (Opsahl, Visualization vs. Communication, 2013). This concept was developed as a means to reduce procurement and lifecycle costs. The DoD defines Model Based Enterprise (MBE) as, "a fully integrated and collaborative environment founded on 3D product definition, detailed and shared across the enterprise, to enable rapid, seamless, and affordable deployment of products from concept to disposal." (Model Based Enterprise, 2014) Experts estimate savings from MBE to be between 50% and 70% reduction in non-recurring costs and as much as

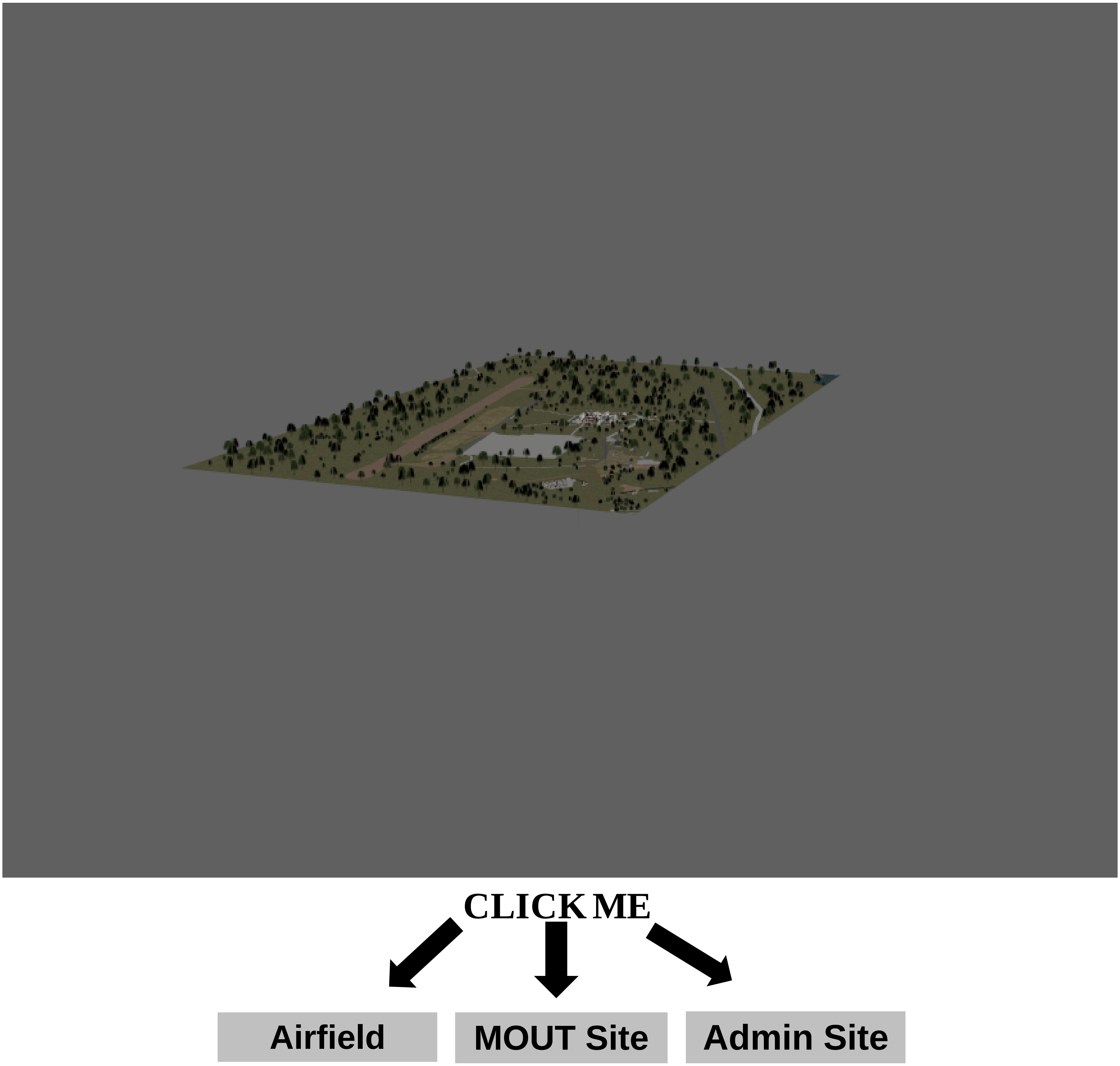

Figure 1: 3D GeoPDF of McKenna MOUT at Fort Benning, GA. Interactive buttons are used to view various areas of interest within the document.

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50% acceleration of time to market in manufacturing applications (Opsahl, Visualization vs. Communication, 2013). More information and resources on MBE can be found at www.model-based-enterprise.org.

In 2011, a group of end-user companies, independent software vendors (ISV's), and systems integrators (SI's) formed the 3D PDF Consortium to assist in the adoption of 3D-enabled PDF solutions, provide educational resources, and serve as the voice of the broader community (3D PDF Consortium, 2016). The consortium has published numerous reports and white papers on topics ranging from 3D PDF comparison to other 3D formats (Opsahl, Positioning 3DPDF in Manufacturing, 2013) and guides for organizations looking to implement 3D PDF in the engineering and manufacturing processes. Additional information on the 3D PDF Consortium can be found at www.3dpdfconsortium.org.

The medical and biology communities have also recently adopted 3D PDFs as a tool for surgical instruction and improved visual diagnosis methods. Van de Kamp *et al*. discuss utilization of 3D PDF as a means to better understand arthropod appendages. They found that the interactive and animated elements 3D PDFs were superior knowledge transfer tools over traditional closed 3D model formats and digital movie files (van de Kamp, dos Santos Rolo, Vagovicˇ, Baumbac, & Riedel, 2014). Ruisoto *et al*. utilize 3D PDFs as a means to prove that 3D spatial visualization is a more effective way for learners to identify the anatomy of the human brain over traditional 2D cross-sectional visualizations (Ruisoto, Antonio Juanes, Contador, Mayoral, & Prats-Galino, 2012). Mavar-Haramija *et al*. implement 3D PDFs as a teaching mechanism for neurosurgeons. They describe the use of 3D PDFs for preoperative planning that allows neurosurgeons to perceive, practice reasoning, and manipulate 3D representations of a human skull (Marvar-Haramija, Prats-Galino, Juanes Mendez, Puigdelivoll-Sanchez, & Notaris, 2015).

Purpose

This paper is organized into three major sections. The first major section describes the innovative applications and on-going usage of 3D PDFs within the DoD modeling and simulation (M&S) industry as experienced by the authors. The areas we discuss are verification and validation (V&V), mission planning and rehearsal, 3D content preview, and mobile applications. The second major section focuses on the authors' process for generating 3D PDF content. This section is further separated into two subsections describing the generation process for 3D terrain and models, respectively. This second section seeks to provide would-be adopters of this technology with awareness of the tools and skillsets necessary to generate 3D PDF documents. Finally, the third major section describes the results of the authors' 3D PDF utilization, to include cost, schedule, performance, and user feedback.

APPLICATIONS

The Background explored the emerging use of 3D PDFs within the medical science, engineering, and manufacturing industries. The authors' focus will be on applications of 3D PDFs to the DoD modeling and simulation community and both the potential and realized benefits they can offer.

Verification and Validation

The primary motivation for the development and implementation of a 3D PDF capability was for the purposes of Verification and Validation (V&V) of both 3D models and synthetic environment representations (i.e., terrain). This is an innovative approach to traditional V&V techniques that has the potential to significantly increase the utility of the end product while reducing costs associated with test and evaluation.

3D Model V&V

Traditionally, SE Core 3D models, referred to as Common Moving Models (CM2s), have been validated over the now discontinued Defense Connect Online (DCO) collaboration service by a panel of training and weapon system subject matter experts (SMEs). This was accomplished by sharing a model developer's desktop across the internet to a virtual expert panel for review. In real-time, the model developer was able to manipulate position, annotate, and often quickly edit the models at the request of the experts.

The replacement of DCO by the Defense Collaboration Service (DCS) application has eliminated this previous capability. In our experience, while DCS is a more cost effective solution for DoD online collaboration utilizing common word processing and presentation applications, the bandwidth necessary for real-time refresh of high resolution desktop streaming is not sufficient. Inconsistent connections and poor refresh rates have caused frustration from our subject matter expert (SME) panel and have even lead to reduced SME participation, which greatly affects the ability to sufficiently accredit models for training use.

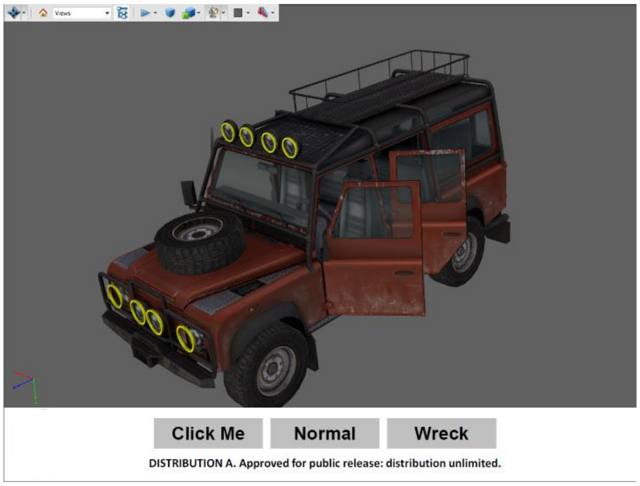

Figure 2. 3D PDF generated from an SE Core 3D moving model (Land Rover Defender).

Implementation of 3D PDFs in the 3D model V&V process has mitigated the limitations imposed by DCS. We are now able to provide 3D PDFs of models to SME participants at various stages of model development in order to acquire expert feedback early and often. Additionally, the intuitive nature of the 3D PDF interface allows the experts to manipulate the 3D PDF documents themselves without any advanced training; a 13-page 3D PDF user's guide is provided with all document deliveries to the SMEs. The 3D PDF generation tools also provide the capability to identify light points and animate the articulating components of a model at their respective degrees-of-freedom (DOFs). Figure 2 (note that Figure 1 is the only available 3D PDF in this paper) illustrates an example of a 3D PDF model provided to SMEs for feedback.

Synthetic Environment Representation V&V

Like 3D models, synthetic terrain representations can also be converted into an interactive 3D PDF document. This capability has revolutionized how V&V for terrain is executed. The benefit that 3D PDFs provide to this V&V process is twofold: (1) mitigation of declining travel funds and (2) ability to obtain increased SME feedback. Figure 3 illustrates how 3D PDFs are being utilized in the SE Core terrain V&V process.

The decline in the funds available for DoD travel has created manpower and schedule limitations for SMEs to participate in SE Core Integration and Test (I&T) milestone events. This limits the amount of iterative SME involvement (time and personnel) that can be obtained because I&T of terrain can only be conducted at the SE Core facility due to software and hardware infrastructure requirements. This reduced SME involvement results in stakeholders and SMEs having to put an increased trust in SE Core to repair issues identified during I&T events without being able to physically verify them until the final product delivery. This limitation can be alleviated through the generation of 3D GeoPDFs for the major terrain issues identified that require stakeholder concurrence. Small file size and a common, standardized format allow these documents to be sent over email and easily read by receiving stakeholders using commonly available applications like Adobe Reader or Adobe Acrobat®; applications available on most DoD computers.

We have yet to find the upper bounding limits for a terrain size that can be generated with the 3D GeoPDF process. Currently, the only limiting factors are processing time and resulting file size. On average, a single terrain tile measuring 8.489 km-sq can be generated in approximately one hour at 4.6 megabytes although this may fluctuate based on terrain content within the tile. This means that multiple terrain tiles can be generated as a single 3D GeoPDF. These large terrain extents can then be provided to SMEs as a pseudo 'read-ahead' package prior to physically participating in milestone I&T events. The 3D GeoPDFs contain the exact same content as the simulation format from which they were generated; albeit without the engine-specific effects (lighting, shadows, etc.). This terrain read-ahead capability allows for increased SME feedback beyond what was

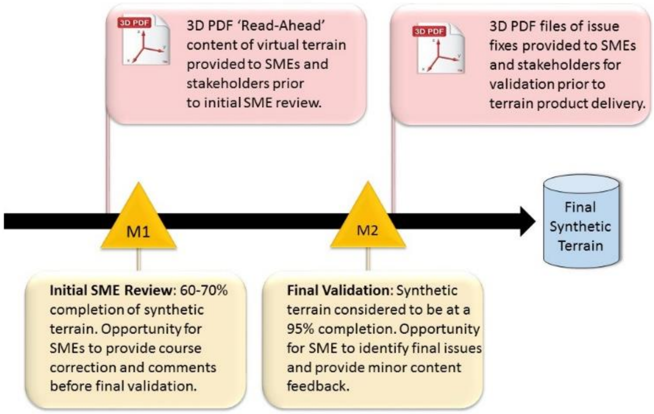

Figure 3. Example 3D PDF implementation into the SE Core synthetic terrain validation process.

previously available. Funding prevents stakeholder groups from sending a large amount of SME personnel to contribute to a physical test at a developer's facility. Through this innovative use of 3D PDF technology, these same stakeholder groups can now circulate entire portions of terrain internally to their organization in order to solicit feedback to be provided to the key personnel traveling to attend the test event. Key stakeholders at the stakeholder organizations can also use these 3D GeoPDFs to generate presentations and demonstrations for leadership within their organizations. This was previously only able to be accomplished through the use of screenshots provided by SE Core to the target organization.

While each of these two V&V applications is framed in an SE Core centric use case, it is logical that any virtual terrain or model production organization can apply these 3D PDF processes within their own V&V methodology.

Mission Planning and Rehearsal

Printed maps have long been used by the simulation community for exercise scenario planning and generation. Simulation operators provide a standard (2D) PDF map of the terrain 'play box' to the operational unit commander for annotation. This annotated map is then utilized to generate a scenario for the simulation exercise. In late 2014, the TRADOC Program Office (TPO) for terrain removed SE Core's requirement to generate correlated printable PDF maps as a deliverable for synthetic terrain products due to costs and the availability of National Geospatial-Intelligence Agency (NGA) Compressed ARC Digitized Raster Graphics (CADRG) products. Although these NGA map products are highly detailed, they are often out of date. Furthermore, they do not correlate with the content represented in the synthetic environment due to the addition of simulation-specific geospatial data. This reduced capability has negatively impacted the ability of the simulation operators to efficiently generate scenarios and provide commanders appropriate situational awareness of the geographic area.

3D PDFs have the potential to fill the gap left by the removal of the standard 2D printable PDF map requirements as well as add increased functionality. The most significant difference is the ability for a 3D PDF user to 'turn off' any part of the terrain or structures. The integrated 3D PDF application tools allow users to toggle on or off any element within the 3D PDF. This is extremely useful for urban environments and megacities, where operational commanders can view each floor plan of a building by turning off various floors and walls. This allows for advanced urban operations planning at the entity level not previously able to be accomplished using standard 2D CADRG maps. Figure 4 demonstrates an example of an urban environment where this toggle capability has been applied to a building to expose the underlying floor plan. 3D PDF maps offer other obvious advantages over their 2D counterparts. Given a 3D PDF of a target mission area, the user can quickly identify terrain elevations without having to decipher contour lines. 3D PDFs also offer the advantage of viewing additional content not typically shown in detail on traditional CADRG maps, such as individual tree or other vegetation placement, building and structure characteristics (height, color, etc.), airfield details, as well as many other three-dimensional elements. This can be a useful capability when planning gunnery and maneuver on a virtual training range. Utilizing the 3D GeoPDF, a commander can view locations of battle positions, targets, and additional range infrastructure not typically represented on the CADRG maps. Figure 5 provides an example of this on a Digital Multipurpose Range Complex (DMPRC) live-fire range.

Outside of simulation, 3D PDFs also have applicability in the operational military environment, especially for quick reaction forces. Given geospecific geographic information system (GIS) data, mission planners can quickly render a 3D terrain representation and export it as a common 3D GeoPDF. The portability of the 3D PDFs allows it to be electronically provided to field deployed units for advanced planning on a 3D representation of the area of operations or for study during down time prior to deploying for a mission. This capability can provide warfighters with the following advanced situational awareness:

- Understanding lines of sight
- Detection of infiltration and exfiltration routes
- Identification of high terrain
- Identification of cover, concealment, and obstacle features

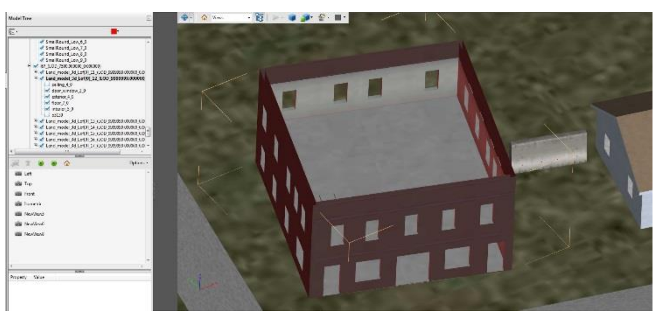

Figure 4. Using the built-in model tree hierarchy in 3D PDFs, buildings can be "opened up" revealing the underlying floor plan

This operational application of 3D PDFs has been utilized by special operators of the Joint Special Operations Task Force-Afghanistan (CJSOTF-A) to develop 3D intelligence models of high-value targets and terrain.

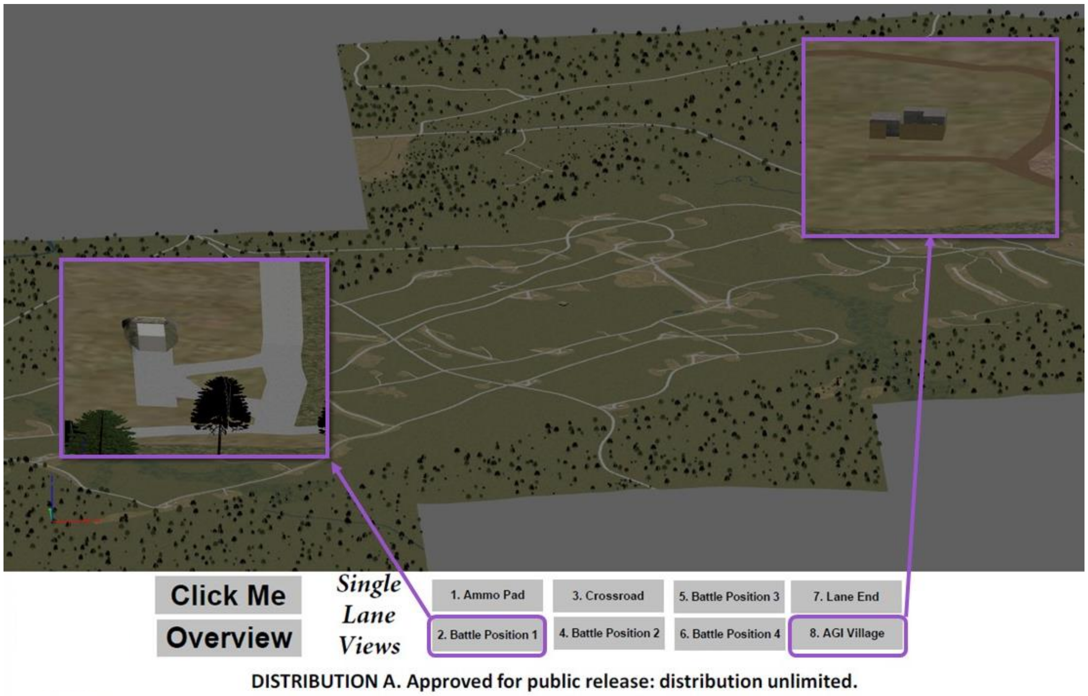

Figure 5. 3D GeoPDF of the Fort Benning Digital Multi-purpose Range Complex (DMPRC) illustrating the ability to add PDF Bookmark Buttons to quickly view elements within document: Battle Position (left) and Air-Ground Integration Village (right).

3D Content Preview

3D PDF technology provides a powerful capability to preview synthetic terrain and models. SE Core posts most of its synthetic terrain and 3D model products on web portals for download by approved DoD entities. These files, especially virtual terrain formats, can be many gigabytes in size depending on the target simulation system and geographic terrain extents. Downloading these large files on standard DoD hardware and networks may result in lengthy download times. Once the download completes, organizations may find that either they have downloaded the wrong file or the terrain and model contents do not meet their specific use case. 3D PDFs can be deployed to solve this deficiency through an implementation that has been termed “3D Thumbnails”. A sample 3D PDF can be generated to correspond to a posted terrain format and because of the small file size and portability, a prospective user could quickly download the 3D PDF to evaluate if the corresponding true file contents will meet their needs.

Figure 6. Two examples of 3D PDFs Displayed on Apple iOS Mobile Operating System

Mobile Simulation and Training Applications

The portability of 3D PDFs can also be leveraged within mobile computing environments. Because these 3D PDF documents are truly system agnostic, they can be opened on both Android® and Apple® standard operating systems through any number of freely available PDF reader applications. Figure 6 provides an example of both terrain and model 3D PDFs within an Apple iOS™ operating system. 3D PDF integration on mobile devices has a number of potentially useful applications in the simulation and training domains. One example is the use of 3D PDF models as a training or reference aid for mechanics and maintenance personnel. A high-resolution vehicle or device model could be generated as a 3D PDF that would allow users to manipulate and interact with components virtually to understand interactions between components. The ability to use this capability on a mobile device means that users can have the information readily available for reference while they perform the required physical maintenance.

The implementation of 3D PDFs of terrain onto mobile platforms poses additional training benefits. This capability complements the earlier discussion of 3D PDFs utilized by deployed users in operational environments for mission planning and situational awareness.

PROCESS FOR GENERATING 3D PDFS

SE Core uses a combination of commercial off the shelf (COTS) software tools to generate 3D PDFs and GeoPDFs. Presagis Creator™ is a 3D modeling software optimized for natively processing OpenFlight data. Okino PolyTrans™ and SAP Visual Enterprise Author™ can be used interchangeably as tools to visualize, translate, and optimize 3D content. Adobe Acrobat Pro™ is a standard application for creating PDF documents. TerraGo® offers a suite of plugins for Adobe Acrobat Pro and Adobe Reader. TerraGo 3D Composer™ is a plugin for generating 3D GeoPDFs, TerraGo™ Software Development Kit (SDK) is an SDK to integrate TerraGo GeoPDF generation into a user's third-party applications, and TerraGo™ Toolbar is a plug-in that allows users to update and manipulate GeoPDF maps and imagery. Finally, Autodesk Maya™ is used to animate, render, and illuminate 3D models.

3D GeoPDF Generation Process for Terrain Areas of Interest (AOIs)

3D PDF generation of terrain AOIs is the process of converting OpenFlight insets of terrain databases to Universal 3D (U3D) outputs to then convert to PDF for easy viewing and sharing. The PDF output gives data consumers a 3D insight into the terrain database without having to use a terrain database viewer. The 3D PDF also provides additional metadata for a given database and provides navigation of an area within a terrain database using Adobe Reader. Geo-registration of the 3D PDF enables spatial information to be viewed in Adobe products using the TerraGo tools and toolbars. A geo-registered 3D PDF, or 3D GeoPDF, allows users to perform spatial calculations and measurements along with getting location and elevation information of the desired content.

The process of generating 3D GeoPDFs for Terrain AOIs is not complex. SE Core uses commercial tools to convert exported OpenFlight content into 3D PDFs and utilizes additional tools for the geo-registering process. This section highlights each step of the process in high level detail. Figure 7 illustrates the SE Core process for generating 3D GeoPDFs of synthetic terrain.

One of the most critical parts of the 3D GeoPDF generation process for terrain is to accurately determine which OpenFlight block needs to be processed. This can be a time consuming because terrain AOIs often reside between multiple OpenFlight terrain blocks. A thorough knowledge of your organization's synthetic environment development process and the geospatial tools utilized are necessary to determine the location and boundaries of these OpenFlight blocks. Once OpenFlight blocks are identified, they must be prepared and pre-processed for conversion. SE Core utilizes Presagis Creator software during this step due to its native support of the OpenFlight format. With some of the constraints by the Adobe software, additional items need to be performed to the OpenFlight block for some of the content to display correctly. Double-sided face objects such as trees and barriers need to be edited in Creator and have their faces reversed so that the content will be visible in the final 3D GeoPDF using Adobe. Additional actions performed include: deleting extra nodes associated with the OpenFlight to reduce resulting file size, merging multiple OpenFlight blocks together, and cutting blocks down to a manageable size for processing.

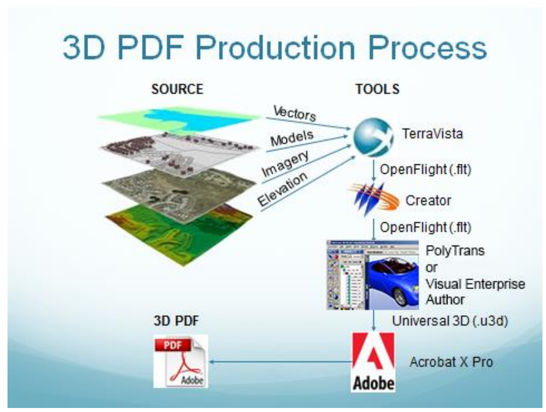

Figure 7. SE Core Example 3D PDF Generation Process for Terrain

Once the OpenFlight blocks are pre-processed, they need to be converted to U3D for integration into Adobe Acrobat. SE Core leverages the PolyTrans or Visual Enterprise Author tool for this conversion. This software is strictly used for conversion and no editing of the data is performed using this tool. The interface is user-friendly for simple OpenFlight import and U3D export using options. The default settings should perform the conversion correctly but updates can be made easily. Once the U3D content is produced, Acrobat Pro can import this content directly for users to actively visualize the content and export into PDF. Acrobat Pro is the final viewer and editor of the 3D content because the Adobe Acrobat Reader software will be the most common application for viewing 3D GeoPDFs. During the U3D import process using Adobe Pro, settings need to be applied to enable orthogonal views in the 3D toolbar for enhanced content viewing.

After import of the U3D, additional enhancements can be made to the 3D GeoPDF using Acrobat Pro. SE Core implements a Microsoft PowerPoint™ border around the 3D view which helps to frame labels, bookmark views, and enable interactive buttons. Acrobat Pro has the capability to allow generation of interactive buttons using their tools for linking views that are created by the Adobe 3D toolbar. These buttons can be useful to re-size the view of the 3D content or zoom to a view quickly for faster navigation of the content. The button generation process is extremely user-friendly. Geo-registration is an additional enhancement that can be made to the 3D GeoPDF which allows users to spatially interact with the 3D content. Measurements and coordinate information can be easily viewed with the utilization of TerraGo software, a set of plug-ins to Adobe Acrobat. SE Core has determined that the TerraGo SDK and custom scripts were needed to perform the correct calculations for the geo-registering process to work with terrain data. Using Acrobat Reader software and the TerraGo toolbar, the geo-registered content can now be utilized and spatially manipulated.

Figure 8. OpenFlight to 3D GeoPDF of CDT Fort Bliss Terrain Database

It is important to note that this process can be followed utilizing any standard OpenFlight content, regardless of its content or the source software utilized to produce it. In order to demonstrate this, we have obtained a raw OpenFlight terrain file of the Fort Bliss automotive skills course from the Common Driver Trainer (CDT) program and generated the resulting 3D GeoPDF seen in Figure 8. CDT is a program of record under the U.S. Army PEO STRI.

3D PDF Generation Process for Static Models and Common Moving Models

All content represented in a 3D PDF must ultimately exist first as a 3D model. Like terrain data, 3D PDF generation of models requires preliminary preparation of the data. As with any data transformation, this can represent a bottleneck for disparate data. The variation between models can influence the amount of effort required to translate content into 3D PDF form. Effort can be reduced if model simplification occurs earlier in the workflow, although unavoidably unique aspects of 3D models can be a highly limiting factor.

A primary cause of model structure and content variation is model usage. For models associated with a particular geospatial location, such as buildings, the production workflow is similar to the terrain generation process of a 3D GeoPDF as outlined in the previous section. However, for models not coupled with a location, the workflows is significantly different. This is usually the case with vehicles, aircraft, and lifeforms—models referred to as "common moving models" or CM2s. Figure 9 illustrates the high-level process used by SE Core to generate 3D PDF models.

Specifics of workflows involved with generating models can induce special PDF preparation steps. Usually the differences take the form of tools required to prepare model content, which may be off-the-shelf, fully customized applications, or even a combination of custom and off-the-shelf. Use of models for terrain generation requires the use of a packaging tool and because these models are in OpenFlight format, Presagis Creator is used to prepare them for PDF form.

Variation in the model hierarchical structure will require special PDF preparation steps. Given that models tend to be highly complex, tools required to prepare or convert them to PDF form may not understand all node types or possible organizations allowed by a given model file format. In these cases a model requires editing of its hierarchy to remove these exotic components. Editing of model hierarchy can be accomplished in either PolyTrans, Visual Enterprise Author, or Maya. Model content not intended for viewing can create visual anomalies and add unnecessary complexity to hierarchy inspection in PDF form and may also require removal.

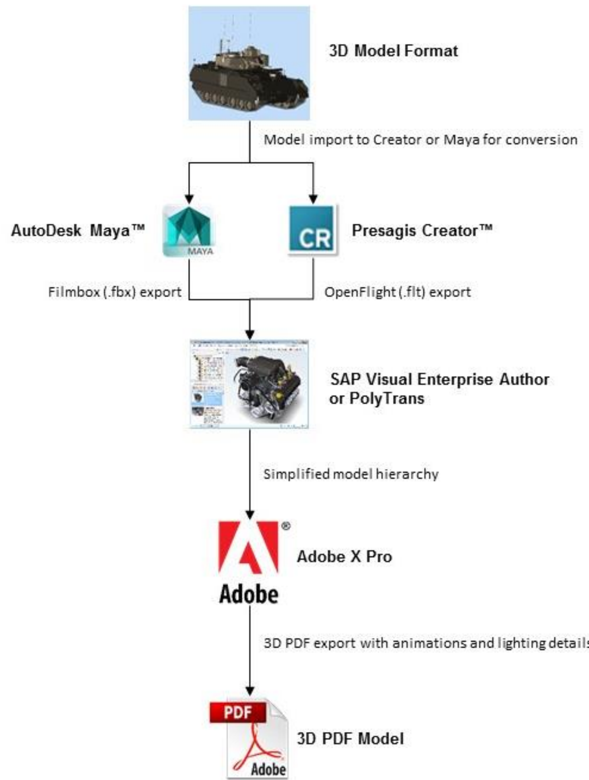

Figure 9. SE Core Example 3D PDF Generation

Model capabilities represent another driving factor of model structure and content variation. Articulated parts, dynamic state representations, and light source representations are some of the capabilities that can lead to additional required steps to prepare PDF content. Articulated parts can be animated within a PDF, however Adobe Acrobat provides only one animation playback control. This requires preparation steps within a model editor to map multiple animations to be viewed into a single animation timeline. Dynamic state representations, such as damaged states, require similar special attention. They take the form of alternate model sub-hierarchies. These can be structured into a PDF to support either manual inspection using Acrobat's hierarchy controls or automated with buttons and custom Acrobat JavaScript. Representing 3D model light sources adequately in a PDF can be a similar challenge. Most tools that translate content into Adobe's supported 3D formats (Universal 3D and Product Representation Compact) are challenged with translating model light sources into U3D/PRC format while utilizing supported format capabilities to preserve light attribution. Options here include simplifying lights through model editing or replacing them completely with graphical annotation.

RESULTS ANALYSIS

Cost, Schedule, and Performance

The benefit of this capability cannot be easily measured by metrics or tangible results though these can be extrapolated based on the imploring organization. For SE Core, the primary benefit that 3D PDFs provide is an increased knowledge transfer of terrain and 3D model contents provided to SMEs or stakeholders. Because funding constraints often preclude large groups of validation authorities from traveling to validation events, 3D PDFs can be sent as a read-ahead data package to provide an opportunity for feedback from outside the core group of validating officials. While this could be abstracted to savings in travel costs, this will largely be determined by the organization utilizing this capability.

From a schedule perspective, SE Core has been able to generate estimates for the time required to generate 3D PDFs from both a base OpenFlight terrain tile containing SE Core content and raw 3D static and moving models. Table 1 provides an analysis performed to determine the time required for both a novice and an expert to generate 3D PDFs of terrain and 3D models. Because the generation of 3D PDFs inherently requires a familiarity with advanced 3D modeling and terrain software, we define a novice as an experienced individual in the M&S developer community who has never generated a 3D PDF before using a documented process, but has proficiency in terrain generation and 3D modeling toolsets.

Table 1. 3D PDF generation times between Novice and Expert Users

Skill Level:	Terrain AOI Single OpenFlight Block (hrs.)	1 Moving Model FBX (hrs.)	1 Static Model FLT (hrs.)
Novice			
Set-Up Time	1	6.75	0.95
Processing Time	0.5	0.25	0.05
Final Enhancements	1	1	1
Total Time	2.5	8	2
Expert			
Set-Up Time	0.25	1.5	0.2
Processing Time	0.5	0.25	0.05
Final Enhancements	0.25	0.25	0.25
Total Time	1	2	0.5
Area in Sq. Km.	8.489	N/A	N/A

User Feedback

Since maturing this capability, the SE Core program has integrated the 3D PDF capability into the verification and validation (V&V) process for two terrain generation efforts: the Joint Readiness Training Center (JRTC) and Joint Base Lewis-McChord (JBLM). Feedback from these installations have been positive. Representatives from the JRTC mission training complex (MTC) have found that the 3D PDFs are advantageous for circulating terrain AOIs for feedback to external stakeholders outside of the MTC. On the topic of 3D PDFs as a V&V tool, the reviewers have commented that the clarity of the 3D PDF documents allow them to efficiently verify that an issue was fixed as requested. They have also utilized the 3D PDFs as a tool for briefing leadership on status of terrain development. When queried on additional thoughts, the JRTC MTC identified benefits that 3D PDFs could provide to mission planning:

> *"I would have loved something like this, during mission planning when I was in the Army, these would give you a lot of detail that is normally missing" – Ronald Sellers, Fort Polk Modeling and Simulations Specialist*

The JBLM MTC commented on the utility of 3D PDFs as a briefing tool to leadership and is investigating techniques to imbed them into PowerPoint presentations. Both installations have also provided feedback on how to improve the usability of these documents. JBLM has recommended implementation of more intuitive controls for navigating the 3D PDF terrain and JRTC suggested enhancements for geographic situational awareness, such as overlaying the 3D PDFs onto 2D imagery within the document.

We have also demonstrated early prototypes of the 3D GeoPDF documents to armored maneuver SMEs within the virtual collective simulation domain. This capability was met with positive feedback by the SMEs who identified potential applications to simulation exercise creation, gunnery mission rehearsal, maneuver planning via map overlays, and the potential for cost and schedule savings versus 2D paper map annotation. We plan to engage additional SMEs across multiple simulation and training platforms as we continue to mature this 3D PDF capability.

CONCLUSION

In this paper we have presented several innovative applications of the emerging 3D PDF technology as a tool to positively augment the DoD M&S community and beyond. Additionally, we have provided guidance and a high-level 3D PDF generation road map for users looking to adopt 3D PDF technology into their own processes. In our early applications of this technology, we have received positive feedback from stakeholders and users on the benefits of portability and interactivity of the 3D PDFs provided. We have also received feedback on areas of improvement and suggestions for enhancement to make this an even more powerful tool. This feedback will help us to better integrate this technology into our official terrain and model generation process as both a V&V tool and perhaps a formal delivery format. Additionally, observation and continued implementation will be required to fully understand the long-term cost and schedule benefits of this technology to our program, but short term impacts have proven encouraging.

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