CRAFTING THE DIGITAL:
3D IMAGING AND MODELING PROTOCOLS DEVELOPED FROM THE DIGITAL RECONSTRUCTION OF THE RIDEAU CHAPEL

M.Jemtrud, V. Prabhu, J. Hayes, R. Attar

Carleton Immersive Media Studio, School of Architecture, Ottawa, Canada - (michael_jemtrud@carleton.ca, vprahbu@cims.carleton.ca, jhayes@cims.carleton.ca, rattar@cims.carleton.ca)

KEYWORDS: 3D imaging techniques, user dependent modeling, workflow protocols

ABSTRACT:

The inaugural project of the "Digital Architectural Reconstruction Program" is to digitally re-construct and capture a high resolution, accurate, and interactive model of a lost, historically significant building and urban area in Ottawa for heritage and museological purposes. In addition to creating significant cultural digital artifacts, the production of this content exemplifies the digital workflow from acquisition to creation and deployment while simultaneously testing, developing, and integrating the various technologies utilized. The primary building to be digitally reconstructed is the Chapel of the Convent of Our Lady of the Sacred Heart (a.k.a., Rideau Chapel). The project deliverables include a high-fidelity, interactive rich media presentation that imaginatively and critically situates it in its historic, conservation, and museum context.

The research develops new media technologies and techniques in the acquisition, high-performance visualization, production, and overall workflow in the digitization of existing conditions and re-construction of a lost context. The project serves in the technological advance and development of 3D imaging and modeling techniques. The large data sets associated with the project are the primary material utilized in this research that promises to greatly impact the viewing, production, and manipulation of such visually intensive artifacts. Lastly, the material has been used to determine a scalable, hybrid production and deployment protocol for the seamless integration of various digital files with digitally constructed models, image modeled components, and 3D laser scans. Through this creative process, which oscillates between the mediated and the made, it stands as an exemplar of the crafting of a digital artifact for the sake of engaging the imagination to inspire insights and musings of a historical situation.

Figure 1: Print renderings utilizing wireframe to show distinction between carved and milled moldings on column capital.

1. INTRODUCTION

1.1 Project Introduction

The Digital Architectural Reconstruction Program is a Canadian Heritage, New Media Research Network funded program that completed its first year of operation in March 2005. DARP is an initiative of the Carleton Immersive Media Studio (CIMS), an organized research unit within the Carleton University School of Architecture. The research agenda of the interdisciplinary group assumes an intertwining of project-based and applied research that, in the case of DARP, engages in the digital re-creation of cultural heritage artifacts. The team explores and investigates the creation of virtual and built environments with digital media technologies as they concurrently transform and are transformed by our perceptual and epistemological worlds.

The historic building in question is the Chapel of the Convent of Our Lady of the Sacred Heart (a.k.a. "Rideau Chapel"). The Convent was razed in 1972 but the interior of the Chapel was dismantled and subsequently reassembled in the National Gallery of Canada. Besides the partial extant artifact, scant archival narratives, drawings and photographs were used in the evidentiary framework of the reconstruction. The overt intention of the research was to digitally re-construct the Convent, Chapel, and urban area for heritage and museological purposes.

The project deliverables included a high-fidelity, interactive rich media presentation of the Rideau Chapel. The maximum visual fidelity requirements were based on a maximum deployment utilizing a high-performance visualization cluster driving 9.2 million pixel screens. The data set has millions of polygons, multiple media files, high resolution textures, and dynamic lighting.

The research-creation attempted to define a workflow from digital acquisition of extant artifacts to the display of high-fidelity 3D models and animations. The fusion of a diverse set of media files, from text, sound, photographic images to animations, QTVR, renderings, and 3D models was achieved both as a means to a greater sophistication of the primary 3D assets as process work and as constitutive of the final multi-media products. The crafting of the digital artifacts in terms of their visual sophistication was paramount. Beyond simple documentation or objects of analysis, the resultant products were intended to perform as imaginative variations that would inspire insights and musings of a historical situation.

2. TOOLS AND TECHNIQUES

2.1 Criteria and Applications

An intention of the research was to minimize the various applications necessary in order to effectively and efficiently construct and present virtual environments of existing or lost buildings. Issues such as speed, accuracy, cost, flexibility, scalability, and desired output modes must be weighed. Concerns in selecting the tools to be employed include:

- data collection to cover all necessary details and material qualities;
- degree of visual fidelity (high resolution compositing, rendering, lighting);
- complex and high geometric accuracy and efficiency of model size;
- pre-visualization and maintenance of a visual fidelity at a real-time rate;
- real-time interactivity (design and presentation);
- multimodal output from immersive output to WWW deployment;
- scalability of output, visual fidelity, asset quality, and infrastructure.

A set of software applications were chosen and the integration, interoperability, and functionality were developed in the context of a collaborative work environment where resources, expertise, and knowledge are shared. A number of factors were considered in choosing primary software applications in the workflow including: inherent capabilities; interoperability with other applications; capability to customize interface and functionality; learning curve; support and training; existing community of users; access to research and/or development partners; short and long-term cost; vision and future development; social-cultural context of users and company.

It must be stated that there is no technically objective way to select certain applications over others for such a workflow. Decisions regarding technologies to be implemented are set within a distinct social and cultural context within which, the product, company, and culture surrounding the product operate and envision itself. The decision to use the software as discussed below recognizes this ultimately subjective position. Although several software packages were tested, no single "best" solution is thought to exist and a 'family' of applications was strategically assembled. While a socially and technically informed decision, this somewhat alchemic process is preferred over the endless technological trap of attempting to find the ultimate technology. An even less desirable situation is, if budget permits, to defer the decision and opt for a plethora of like applications assuming a neutrality of media whose usage is simply an issue of individual preference.

ShapeCapture was chosen for image-based 3D acquisition, and modeling. The 3D digital construction of existing physical environments is typically a user demanding, labor intensive process of digitally modeling by manually positioning elements. Although desired during the design phase of a project, there are several drawbacks to this approach when modeling an existing context. "First, the process is extremely labor intensive, typically involving surveying the site, locating and digitizing architectural plans (if available), or converting existing CAD data (again, if available). Second, it is difficult to verify whether the resulting model is accurate. Most disappointing, though, is that the renderings of the resulting models are noticeably computer generated; even those that employ liberal texture mapping generally fail to resemble real photographs" (Debevec, 1996). Image-based modeling and image-based rendering can expedite the process of acquiring 3D data and textures through technological automation. This image-based technique mediates the recovery of geometry from a series of photographs and is well suited to architectural and urban environments as it exploits the rectilinear and perspectival nature of the built world. The benefits of photogrammetry are the fact that is a cost effective and non-intrusive technique capable of recording precise geometric and texture data from the level of overall context to details and engineering analysis. The photographs can be used for archival purposes (El-Hakim, 2003).

The most critical application to select for the workflow was the 3D modeling, rendering, and animation software. Maya and MentalRay were selected for this purpose and in some cases FormZ was used for base modeling. The production phase is the moment in the project when the positive creative slippage occurs and mediation can work to the detriment of the imaginative process. Thus, the software has to be robust, flexible, customizable, and well suited to the architectural imagination. Although Alias Maya is biased toward character animation, the underlying capabilities make it the most powerful application for our purposes. They are sophisticated tools for the construction of models and their rendering, texturing, lighting, and animation. Photo-realism is not always desired by any means but the technical requirements of matching photo-realistic visual fidelity and real-time rendering and interaction sets the hardware and software standard for production and presentation. Maya is capable of sophisticated rendering and animation while MentalRay dramatically extends the rendering and lighting capabilities of the package. Maya Embedded Language (MEL) is an open source scripting language that allows the customization of the interface and functionality of the program. MEL is a scripting language that provides the foundation for Maya operation. MEL commands and scripts can be used to create a number of changes and refinements to the operation and functionality of the application. Further, it is used to transform the user interface.

2.2 Sensor and Modeling Technology: Data Fusion

Multi-sensor, multi-modal 3-D digitization of urban and architectural environments holds immense creative, imaginative, analytic and visual/rhetorical possibilities for architects and urban designers. With current advances in laser scanning, photogrammetry and GIS-related technologies, the integration of 3-D imaging techniques within existing workflows has become a viable and cost-effective solution. The benefits of utilizing multi-sensor data in cultural and existing-conditions documentation allow architects to situate design proposals within accurate and visually convincing contexts.

The 3-D digitization process is a complex undertaking that casts one through a variable and heterogeneous digital landscape of map and survey data, orthographic computer-aided design (CAD) drawings, photographs, 3-D non-contact imaging data (e.g., laser scanning, photogrammetry, etc.) and 3-D models.

With this said, the use and integration of multi-sensor technologies in architectural applications, such as laser scanning and photogrammetry, with traditional modeling, texturing, and animation is not a seamless enterprise. Architectural tolerances and thresholds for metric accuracy, visual fidelity and deployment are different than those of geographers, infrastructure planners, engineers, and facility managers who are more commonly implicated with such techniques. Digital assets conform to type-specific thresholds of precision and visual fidelity, depending on their use and integration into an overall production and deployment pipeline that corresponds to disciplinary skill sets, expertise and intentions.

The varied and multiple information inputs are largely due to intensive visualization requirements, intended use and long-term applicability of the base datasets that are of interest to architects, heritage preservationists and urban planners. The diverse information has a "life of its own" in traditional mapping and fabrication practices capable of being presented in three dimensions.

A key factor in determining the data required is the function of the assets as a simultaneously productive, analytic and visual/rhetorical tool. In most situations, such as engineering analysis or surveying applications, the end users and applicability of such data are specialized and limited.

In the case of architectural models, the stakeholders range from those within the architectural/engineering/construction professions to city officials and the general public. In addition, the metric tolerances range from urban (meters) to Computerized Numerical Control (CNC) fabrication of physical artifacts (sub-millimeter), thus requiring differing technologies for corresponding uses.

As such, visual-fidelity requirements, metric accuracy and the integration of multiple media types are the primary considerations when determining the sensor technologies used and methodologies employed. Also, the efficiency of manipulation and high-performance visualization capabilities must be weighed. A strategic initial acquisition of base data allows the information to be repurposed and does not require revisiting the physical site.

Such a heterogeneous composition of data necessitates a hybrid methodology that is defined by a synthesis of multi-sensor techniques with user-dependent modeling to augment and extend the value of the digital assets.

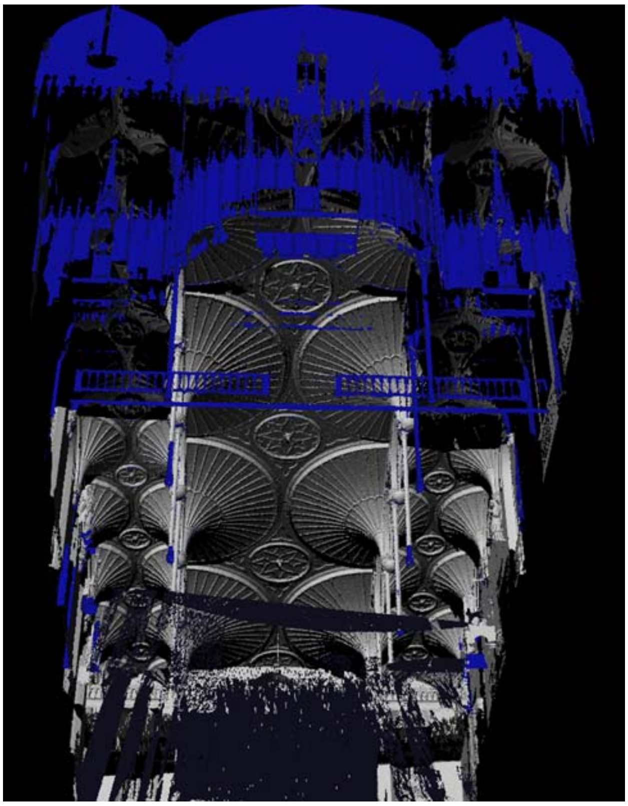

Figure 2: A time-of-flight laser scan was done using an Optech ILRIS-3D LiDAR. Data conversion by Northway Photomap.

Figure 3: A close-range laser scan of altar detail via a ShapeGrabber PLM600 provides a level of detail accurate enough to create realistic reproductions.

3. 3D IMAGING AND MODELING PROTOCOL

These issues were considered in a project that intertwined content-based and applied-research agendas in the digital reconstruction Rideau Chapel. Laser scans of the Chapel's interior, augmented with photogrammetric 3-D models created from archived drawings and photographs, enabled the reconstruction of the context—lost and remaining buildings—in a superior visual fidelity.

The development of a 3-D imaging and modeling protocol, called CIMSp, was accomplished that incorporates multi-sensor technologies with modeling and rendering techniques through a process of interpolation among a heterogeneous set of existing photographic, physical and 2-D documentation.

CIMSp is intended to define a general "best-practices" process that resolves procedural and technical hurdles in situations where integration of 3-D non-contact imaging and user-dependent 3-D modeling of non-extant (proposed or lost) architectural conditions is desired.

It considers the digitization process is total from acquisition to creation and deployment. The crafting of 3D reconstructions is seen as a continual dialog between the mediated and the made. No single technological solution exists at any stage in the process which requires a reciprocal integration, development and oscillation between technologically mediated data sets and user dependent manipulation of digital artifacts.

CIMSp is the core, bi-directional organizing element and umbrella under which the research of the unit is driven. The new media applied research coalesces in the protocol in the form of tool customization and high-performance visualization solutions. Additionally, it reciprocally organizes and propels the content production from acquisition and creation to deployment. The project's intention was to digitally reconstruct a lost heritage building from a partially existing architectural artifact and existing orthographic and photographic documentation. The resulting digital object indicates a scaleable, multi-sensor 3D imaging and modeling approach that's applicable to architectural, urban and heritage decision making; physical artifact reconstruction; and virtual event construction relevant to cultural venues, entertainment, education and design-proposal discussions. The initial acquisition accommodates a high-fidelity and precise output, allowing for the decimation of the resultant data for Web- and screen-based output.

The protocols implemented are a multi-layered and hybrid approach that recognizes the interplay among human scale and perception, visualization and abstraction of data, and geometric accuracy. The challenge is to integrate high-fidelity and precise data acquired from existing conditions through 3-D non-contact imaging with 3-D models of non-extant architectural conditions.

As a general benchmark, the metric accuracy of datasets in regard to existing conditions largely conforms to the phenomenological scale of the artifact in question. For example, in the case of a building envelope or room within a building, accuracy has a larger tolerance than that of an object within a room or architectural detail such a bas-relief or carved molding.

The overall dimensioning of a building can be accurately obtained by a hybrid methodology of traditional user-dependent 3-D modeling and photogrammetry and/or orthorectified photo mapping if a larger urban context is required.

3.1 Layered Approach

In the protocol developed for the project, the primary layer captures the artifact's overall geometry, including large-scale details and urban context. The secondary layer uses survey data from the primary layer to generate more-specific geometries. The tertiary layer uses laser-scan data to capture sub-millimetric geometries.

This layered approach is necessary to ensure a practical balance between a high degree of accuracy and efficiency. The layers are structured in degrees on increasing geometric and textural accuracy and can be followed up to any point, from the macroscopic views of the primary layer to the sub-millimetric accuracy of the tertiary layer.

The benefit of this approach is twofold. It allows for the work to be divided easily among several groups, and it demarcates definitive milestones to occur throughout the digitization process. After completing the objectives in the primary layer, for example, a completed model can be generated that contains all the major geometric details and a large amount of survey data. Completing the objectives in the secondary layer provides a model with a significantly greater refinement and accuracy. Completing the objectives in the tertiary layer provides a model with exponentially greater detail.

3.2 Preferred Sensors

The demands of accuracy and fidelity asserted for architectural applications determine the thresholds to be achieved, thus indicating the preferred sensor technology. To accommodate for the differing scales ranging from urban to CNC milling output, the layers must employ technologies that can be integrated while respecting the requirements of the immediate application.

By utilizing multi-sensor 3-D non-contact imaging techniques from close range and time-of-flight laser scanning to photogrammetry alongside 3-D modeling, the desired accuracy and range of applicability was achieved.

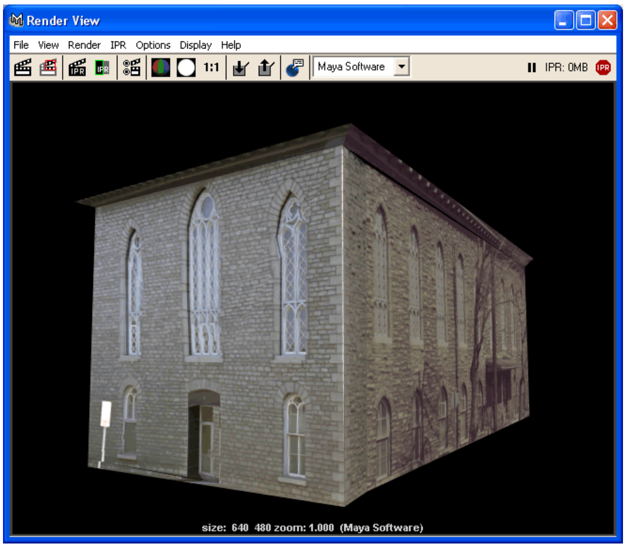

Figure 4: Photogrammetry model composited in Maya.

The photogrammetric reconstruction of the Convent from a limited number of archival photographs was very effective (Figures 4-6). However, issues of efficiency are dependent on practical knowledge, skill sets and the metric tolerances specific to the intended output. In the case of architects, user-dependent 3-D modeling often is more effective than photogrammetry techniques. Photogrammetry proved to be dimensionally more accurate, but it was inadequate or inefficient in acquiring complex geometries as compared to user-dependent modeling.

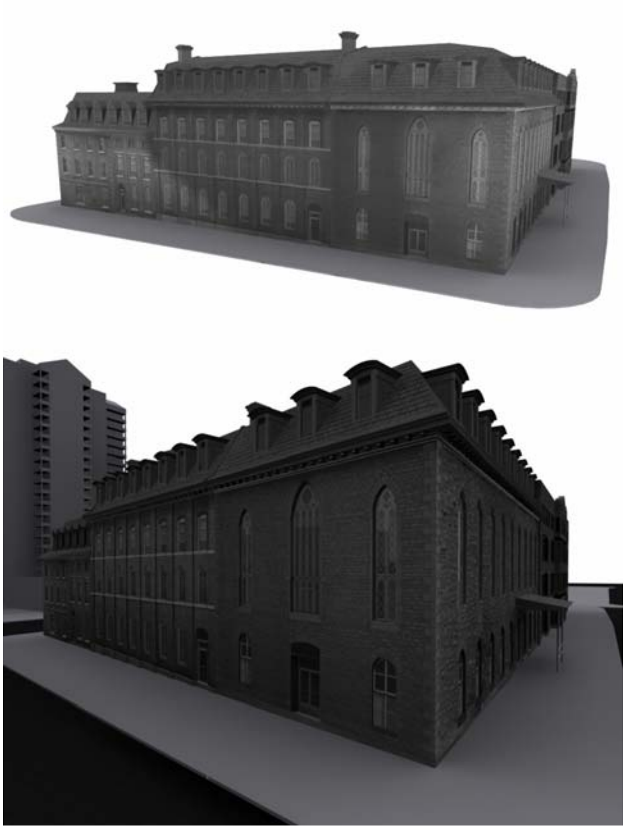

Figure 5-6: External building views were captured through a combination of photogrammetric and 3-D modeling techniques.

The accuracy of the Chapel and various elements with in were confirmed via photogrammetry techniques and derived models as templates and overlays with 3-D modeling, which allowed for more-efficient complex modeling. This process confirmed the inaccuracy of existing 2-D drawings that are typically the basis for current 3-D digital reconstruction. In some cases, such as the altar, a minimal amount of 3D modeling was used to add dimensional depth to texture maps for the animation (figure 13).

A LiDAR scan was taken of the existing space, but it was determined that the additional accuracy was of little benefit to the model over the photogrammetry/modeling hybrid methodology. Metric tolerances are such that the cost/benefit of laser scanning entire structures over 3-D modeling is not typically justifiable unless access to pre-existing datasets is available. The artifact was sufficiently rectilinear for this process, but there are certain cases, particularly cultural heritage, where point-cloud data are necessary due to the amorphous geometry of existing conditions.

Close-range scanning was used to capture intricate carving on the altar (figure 3). The point-cloud data can be used for precise physical fabrication of the details on a CNC milling machine to restore or replace lost artifacts as well as authentication. In several cases, the knowledge and ability to hand-fabricate historically significant artifacts has been lost, so precise documentation through laser scanning is crucial.

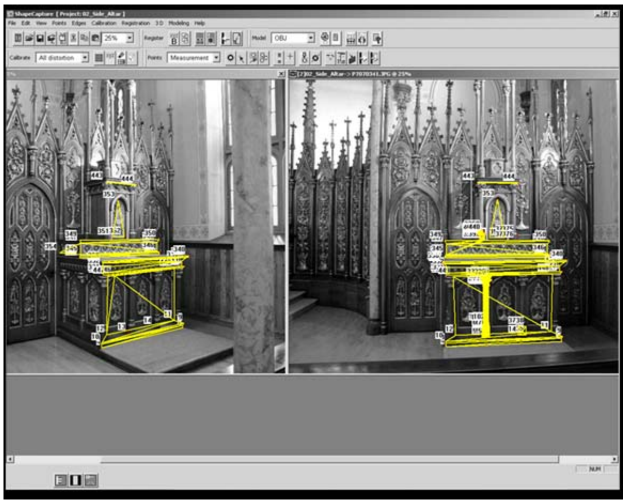

Fig 7: Screenshot of photogrammetry image modeling process.

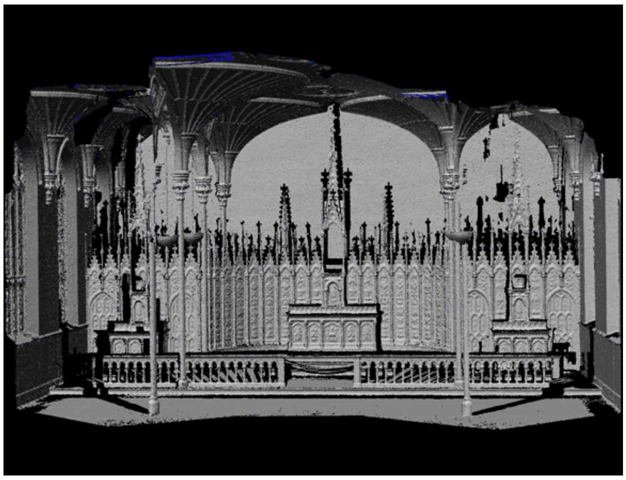

Figure 8: A time-of-flight laser scan.

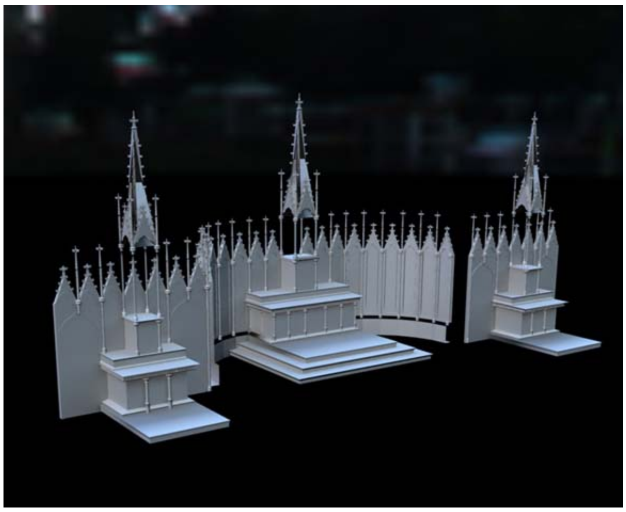

Figure 9: In process 3-D modeling with metric verification from photogrammetry techniques.

Figure 10: Assembled hybrid model before texturing.

Figure 11: Hybrid model of the altar.

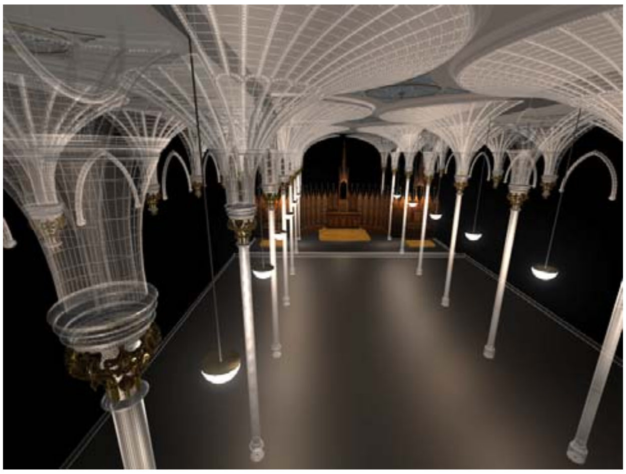

Figure 12: A fusion of datasets from laser scans, photogrammetry, 3-D modeling/texturing.

4. CONCLUSION: CRAFTING THE DIGITAL

The hybrid method articulated combines both geometry-based and image-based techniques to achieve a balance between effectiveness and creativity in the acquisition, documentation, and design process. A creative process is only as good as the positive resistances and efficiencies that it presents to the creator as an oscillation between the realm of technological mediation and the creative, embodied, user-dependent realm of making.

A strategy of choreographing these resistances inherent in the materiality and biases of the media used is a necessary position to take. A balance between the mediated and the made is one that is gained through proper knowledge and familiarity of craft in general, the interrelation of the various technologies involved, and each specific medium.

A keen awareness of the crafting of digital artifacts sets up criteria for identifying (often intuitively) preferred resistances and biases inherent in each application. A balance between the technologically mediated operations of certain software application and the making of a digital model or image first recognizes the inherent biases of the medium in its specificity and then accepts (or rejects) the resistance certain operations submit to the creator.

Combining applications to achieve a desired effect is often more desirable in the design process precisely due to the struggle to overcome technological resistances. The integration of heterogeneous application files is inevitably an issue of translation between applications rather than a transcriptive, technologically mediated action.

The fusion of the various media contributed to the creative process in terms of cross-reference and metric verification while the individual data sets retained their autonomy for specific application. The status of work in the total workflow is a value that must be weighed with the effort and resources committed to acquire the data. The inclusion of various files in the interaction with the material and content asserted their value in the experience of the rich media presentation. The overall result was an integrated 3-D model that incorporated the heterogeneous digital assets as part of the creative process or as tangible artifacts in the final asset.

Figure 13: Final rendering taken from animation.

The use of various modes of abstraction, from wireframe techniques to photorealism, allows for analysis to filmic quality presentation. Due to the integration of multi sensor technologies, the resulting digital artifact allows for the remediation of assets in multi-modal output including high resolution print media to interactive 3D content and animations deployed on a high-performance visualization cluster for high fidelity and immersive environment output. Decimation of the high-fidelity assets was accomplished for rich media DVD, web and standard screen deployment.

Figure 14-16: Detailed interior illustrates a fusion of datasets from laser scans, photogrammetry and 3-D modeling/texturing. Atmospheric lighting in the rendering environment adds a greater degree of realism.

The demands from the architectural and urban design industries place variable and diverse requirements on sensor technology and associated 3D digitization techniques. The requisite skill sets and proficiencies of the discipline and disciplinary tolerances need to be considered in order to determine and customize the tools utilized.

The creative potency, ease and accessibility of the chosen technologies must be appropriate and they must be integrated into existing processes. If the techniques and tools respond to these parameters a robust and skill specific workflow can be determined to produce significant cultural artifacts.

REFERENCES

P. Debevec, C.J. Taylor, J. Malkik: 1996, Modeling and rendering architecture from photographs: a hybrid geometry and image-based approach, Proc from SIGGRAPH'96, pp.11-20.

S.F. El-Hakim: 2003, Critical factors and configurations for practical 3D image-based modeling, 6th Conf. Optical 3D Measurement Techniques, Vol. II, pp. 159-167.

S.F. El-Hakim, G. Roth, and J.-A. Beraldin: 1999, Experimental analysis and design considerations of virtual environments , SPIE Proceedings, Vol. 3641, Videometrics VI, pp. 127-138.

ACKNOWLEDGEMENTS

We would like to thank the faculty researchers and research assistants within the Carleton Immersive Media Studio. Faculty Researchers: Michael Jemtrud (Director), Stephen Fai, Ben Gianni, Lucie Fontein, Gabriel Wainer. Research assistants: James Hayes, Ramtin Attar, Venk Prabhu, Janouque Leriche, Nikolas Beaudin, Nathan Dykstra, Maryam Ghanad, Amanda Gilbert, Jayant Gupta, Jennifer Henderson, Andre Landry, Paul Legomski, Luke MacKay, Flora Mak, Philam Nguyen, Michael Putman, Richard Smith, Edward Solodukhin, Morgan Tang, Nicholas Valenzuela. Additionally: National Research Council of Canada, Institute of Information Technology, Visual Information Technology Group: Dr. Sabry El-Hakim, J. Angelo Beraldin, Fracois Blais, John Taylor, Michel Picard, Luc Cournoyer. Northway Photomap Inc. (Toronto): Stefan Bocsy and Stephen Dixon, Paul Francis. A special thanks to the National Gallery of Canada, Sisters of Charity of Ottawa, Parks Canada, the Heritage Canada Foundation, Alias Systems, IBM.

The Rideau Chapel project was supported and funded through the Canadian Heritage, New Media Research Network fund with additional funding from Carleton University Office of the Vice President Research, Faculty of Engineering and Design, Faculty of Graduate Studies, and the School of Architecture.