Experiencing the Tangible Past through Virtual Reconstruction: Cultural Heritage of Buildings and their Environmental Boundaries

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This paper present the latest techniques associated with reconstructing archaeological and heritage sites on computer. It is important to note that the degree of accuracy needs to meet not only the criteria on the technical aspect of their reconstructions but accurate historical and cultural heritage records as to how the past inhabitant used their living and working environment during that era.

How to capture sound and light signature of the building or space that significantly represents the characteristics of all architectural elements with their contributions to the space within a period of history toward their architecture historical and cultural heritage [1] preservation?

How to visualize the ancient lighting and auralize the audible sounds that show the impact of the architectural elements, and represent the past acoustic and lighting conditions within a virtual environment for their use by cultural heritage specialist [2] or to share their interpretation with general public to experience?

The simulation results should be presented from a given perspective and interpretation also through realistic perception of brightness and loudness of the human audio and visual system at the time. The results presented in this article are based on the number of projects involving cultural heritage reconstruction of selected buildings. The criteria for their selection are based on the unique evident in extreme lighting and acoustic conditions; such as light and dark lighting condition that are experienced in a very unique art museum (Saint Rocco Museum) and room acoustic condition in a small theater (Ostia Theater) relative to a large arena like Roman Coliseum for its crowd noise generated during an event [3, 4]. These new immersive virtual reconstruction techniques in sound and light provide a unique paradigm shift for archaeological interpretation given the accuracy that is available within the modeling algorithm for our audio and visual system as being presented through the latest display technology as being used in CAVEs (Computer Aided Virtual Environments) or latest head mounted display technology [5]. This is a new unique paradigm shift for archaeological interpretation [11-15].

The following sections are attempts to answer the above questions and to demonstrate the ability to visualize and auralize real and simulated conditions within selected cultural heritage sites or buildings. The results present new research approaches in virtual reconstruction utilizing auralization and visualization techiniques that are evolving continuously.

LIGHT

Given the dynamic range that our eyes experience under realistic conditions, the human eyes tolerate wide range of intensities through their ability for adaptation and accommodation as required for luminance adaptation while being responsive to high dynamic range of illumination. The virtual immersive environment allows seeing in dark and light given the display high dynamic capabilities in simulating the range of luminous environment and colors.
New method of eye adaptation based on physiological data that is integrated into the exiting rendering algorithms allows realistic simulation in tone mapping of ancient surface and texture under specific lighting conditions within a period of history using known spectral power distribution of the available light sources [6].

VIRTUAL REALITY as VISUALIZATION TECHNIQUES

The VR is the simultaneous simulation and perception of physical attributes of reality in an interactive, virtual, computer-generated environment in real-time. VR applications in architecture, music, computation, mechanical engineering and medicine have proven to be most beneficial to designers and researchers. The focus of these applications is mostly on the visual and aural aspect of the simulated scenes. In the case of lighting as an example; the major spatial attributes such as surface colors and the lighting system spectral characteristic and its luminance distribution within a virtual environment are simulated and measured while the

Cultural Heritage reconstruction must utilize an integrated approach in its execution of various functions toward preserving the past; yet sensitive and careful enough not to impact the fragile architectural elements that have lasted for centuries. The contemporary features of architectural resilience toward environment are known to professional builders for a long time. The oldest human structures demonstrate or present their resilience everywhere given the current recorded conditions of these historical buildings by archeologists; however their unique engineering solutions to a long lasting life are hidden in dynamics of cultural heritage characteristics as discovered during their recovery and or recent attempts using virtual reconstruction methods.
There are serious challenges to our well-developed building design resilience with respect to architectural construction techniques as compared to our current real and or virtual reconstruction practices. There is a need to retool and examine our abilities and skills in recreation of the past and collective sense of resilience to scale our expectations toward preserving the tangible cultural heritage given the past decades of natural calamities such as earthquake, hurricane, tsunami and nuclear disasters.
Cultural heritage in a given country is unique and irreplaceable. This places the responsibility of preservation on the current generation in that region. The availability of state of the art techniques and expertise in a given field of science is not uniform throughout the world [1]. As of 2012, there are 936 World Heritage Sites in 153 countries throughout the world: 725 cultural, 183 natural, and 28 mixed properties. Each of these sites is considered important to the international community. To transfer the responsibility to a new generation requires the provision of an innovative learning environment. The definitions which apply to cultural heritage are stated below in articles 1 and 2 established by the Venice Charter, 1964 1 [2].
Art. 1: The concept of an historic monument embraces not only the single architectural work but also the urban or rural setting in which is found the evidence of a particular civilization, a significant development or a historic event. This applies not only to great works of art but also to more modest works of the past which have acquired cultural significance with the passing of time.
Art. 2: The conservation and restoration of monuments must have recourse to all the sciences and techniques which can contribute to the study and safeguarding of the architectural heritage.
The scale of environmental impacts on earth life system, the compelling scientific evidence of dynamic changes in local climates and international directives as relates to sustainable developments
and stringent local, state and national legislative or building code requirements (e.g. International Green Building Council (IGBC) and Leadership in Energy Efficiency Design (LEED) for commercial building rating system recognizes that much of a building's in general impact on the environment comes from where it is located and how it fits into its community, etc.) have all contributed to the acknowledgement that education at both pre and post professional levels has a significant role to play addressing these new challenges for Cultural Heritage institutions.

user is experiencing the space, and the perceived brightness of the light sources within the current limitation of the computing power within real time constraints. The post processed and analyzed lighting are displayed in various visualization modes for parametric studies. The data acquisition system allows for the simultaneous recording of the virtual environment and visual response of the users such as their pupil size change due to the lighting intensity and or spectral changes within a scene. The real time measuring capabilities using portable spectrometers allow one not only to record and analyze the conditions with users' reactions, but also to view the spectral characteristics of the light and associated colors reaching the users' eyes. Virtual reality (VR) technique also serves as a tangible, sensible metaphor for structures and phenomena that normally evade the senses due to scale or abstraction. Here the emphasis is on symbolism, clarity, consistency, and strategy in allocating the dimensions of stimulus to the parameters of the structure and its surface or phenomenon [3-6].
The motivation is to develop a cognitive model as a basis for exploration and discovery. Whatever the motivation, the means is sensory stimulation. Progress in virtual reality is measured in terms of the system's capabilities to produce content-rich multi-modal stimuli in real time in response to intuitive (or at least easily mastered) user actions.

The digital environment through computer simulation using on site measured data provides new opportunities and new processes for sustainability and virtual exploration of the building and exchange among researchers in each field. With these opportunities there are also challenges. The research outcome will provide an opportunity for the cultural heritage community to understand these new challenges and shape the future of heritage research.
Current techniques on lighting simulation for building science are based on two decades of computer algorithm developments toward accurately representing common lighting simulation needs [7]. Some of these new techniques are making good progress to provide not only recreation of reality but also reproduction of stimuli within a virtual luminous environment [8- 10]. Simulating complex scenes demand high accuracy for its simulation of colors and spectral characteristics of materials for psychophysics applications. Typically the outcome of such simulations is used as stimuli or alternative to physical simulation with better accuracy when combining freely available and commonly used software by lighting designers.
The interior lighting conditions of the Saint Rocco Museum were measured and photographed using a calibrated digital camera for conversion to RGB and spectral reflectance data. The measured spectral power distribution of the source and surface reflectance provided the path to obtain the RGB signal levels for each of the interior surface characteristic. The illuminance and luminance distribution in horizontal and vertical planes were measured using illuminance, luminance, chorma meters, spectrophotometer and spectroradiometers for both night and daytimes along with a digital camera as a luminance meter [3, 5, 6].
The jugular software was used to create the colors and light sources in a given scene [3, 8-10]. The daylight as a source within simulation software differed only in its atmospheric condition settings. To establish the color of the illuminants, the measured color signals of the WHITE scene for each source were used. All images were rendered with the default values of software except for the number of light bounces, which was set to one within Jugular. The objects or materials in the simulated scenes had lambertian surface properties; material type with specular surface to simulate reflective surfaces such as floor were also used for the complex illumination scenes though the application of Macbeth Color Checker sample because only one point in these scenes was measured at the site at the surface normal. The simulation of the simple Macbeth Color Checker allowed us to estimate and calibrate the RGB differences between measured and simulated scenes [3, 6]. The simulation results should be presented through the perception of brightness and loudness of the human audio and visual system at the time.
For a consistent and accurate analysis, it is necessary to keep the input quantities within a realistic range of real conditions. It is imperative that the input to the rendering models is clearly defined given the limits for each software rending engine and their required input variable, and that the possible range of predicted illuminance and or luminance levels along with associated RGB for a given scene is identified. Simple surfaces with known RGB are simulated as part of the calibration of the VRL projected light or scene passing through the back screen projection using diffuse translucent surfaces. See Figure 1 Left.
Some lighting applications require accurate levels of surface luminance to be simulated as the background in an image and not in the texture of the surface only. The images in Figure 2 show the real lighting conditions as viewed under the museum lighting condition and Figure 3 show the real time spectral reflection of the scenes as viewed by the viewers.

SOUND

The art of room acoustic design is to control the sound propagation through absorption, reflection and transmittance.

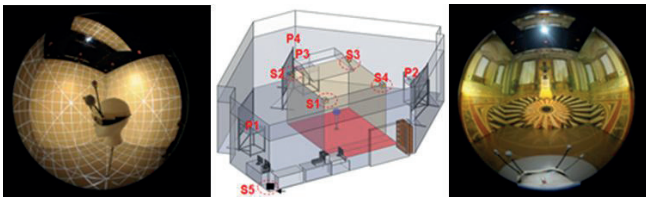


Fig.1 - Real and schematic views of the CAVE's projectors, and output example.

An effective design solution requires the ability to localize the surfaces that create excessive reflection and the main ones that maintain reflected sound energy. Slopped seating reduces audience attenuation and provides good sight lines; which usually means good hearing conditions given that the sound level outdoors falls off only with distance.

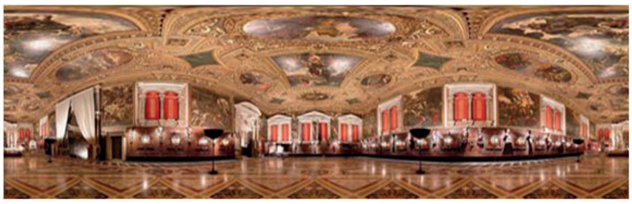


Fig. 2 - Panoramic view of interior.

Fig. 3 - Simulated scenes as shown in a wide angle view of interior spaces created by the software using the average RGB combined with realistic textures and projected for measuring its SPD as viewed in the VR enclosure in real time.

In the real world, the human audio perception experience audio signals in a log scale, a method to visualize and localize the sound that is simulated within a virtual environment using beamforming is presented. The use of an acoustic camera along with noise image software as a short introduction to beamforming method is demonstrated. Furthermore, the transition from the three-dimensional sound recording to the three-dimensional virtual acoustic mapping, visualization and sound perception for its directionality by real subjects within the virtual environment is used to provide realist experience within the historical building such as Rome coliseum.

Prerequisite for this is a 3D-model which can be created quickly within this computer aided virtual environment. Experimental results show that the subjects were able to navigate and locate a real and virtual sound source in a dynamic virtual acoustic environment [20].

The findings from these simulations, auditory navigation experiments via visualization technique within this virtual environment demonstrate the beamforming method combined with human subject data provide opportunities to study sound localization within cultural heritage selected sites and fine tune the current Head Related Transfer Function (HRTF) for various room acoustic design applications. Figure 4 shows the path toward virtual reconstruction utilizing auralization techniques.

FIELD MEASUREMENT: ACOUSTIC CAMERA BASED ON BEAMFORMING

The Acoustic Camera combined with the Noise Image software is an integrated data acquisition system with a unique ability to calculate the sound's position in space. The system provides visualization in 2D and or 3D graphic format of the time and frequency domain measured data utilizing Delay and Sum Beamforming in the time domain using the spherical wave concept. This ability provides an insight to examine and view the frequency and time domain data for Room Acoustic applications. These real time data computation, analysis and visualization capabilities allow the audio engineer and architectural acoustic designers to evaluate and explore the performances of their existing designs or newly constructed projects and or virtual reconstruction of the past [17-20].

Application of immersive Virtual Environment (VE) technology for sound perception is achieved through auditory stimuli based on the results of simulated, auralized, and reproduced sounds within computer-simulated spaces of the existing conditions within cultural heritage site. This immersion capability allows stimulation of all human sensory subsystems in a natural way within this immersive environment. The subject uses special viewing glass and headphones (for best realistic sensation utilizing Head Related Transfer Function (HRTF) with a head-tracking device to listen to the auditory event of a simulated space in real-time while accurate and realistic visual cue are stimulating the user audio and visual systems.

COMPUTER SIMULATION

The hybrid model is the method used in EASEaura, the main computer-simulation software in this research. Briefly, this model can be described as running a specular or reflected ray tracing process which finds a receiver hit by a ray of sound. As the result, the corresponding image source must be audible. The software capability allows historical architectural elements to be investigated for their room acoustic absorption; reflection and transmittance characteristic. See Figure 5 left. Measured results of crowd noise at the site are mapped over the surface seating areas of the Roman Coliseum and are shown in Figure 5 right.

The measurement procedure universally adopted provides an analysis of the impulse response of the environment according to directives given by the reference standard. In this study, the International Team for Acoustics in Cultural Heritage and Archaeology, ITACA, offers an innovative approach that makes use of 3D beamforming for acoustic characterization of ancient theatrical outdoor environments [4, 16]. The use of systems that use this technology in metrology noise is greatly increased, and the computing power

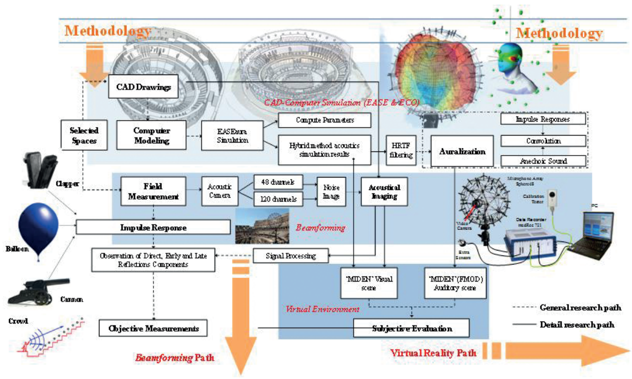


Fig. 4 - shows the path toward virtual reconstruction utilizing auralization techniques.

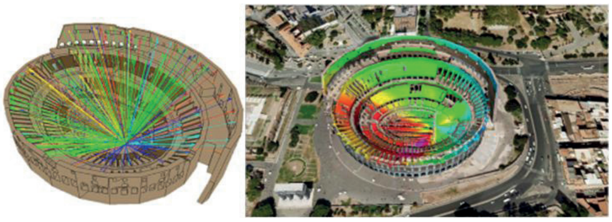


Fig. 5 - Simulated and measured crowd noise propagated within the Roman Coliseum by the utilization of beamforming techniques within real and virtual environment. Red = high, Blue = low sound pressure levels in dBA.

available today allows the transition from acoustic mapping 2D to 3D complex acoustic models [13]. The experimental results concerning the characterization of the noise of the Roman theater of Ostia Antica demonstrate (see Figure 6). The effectiveness of this new experimental approach, which despite some weakness starts to be an alternative to more traditional methods. The amphitheater prototype bridges theater with learning and experiencing the environment in ancient times.

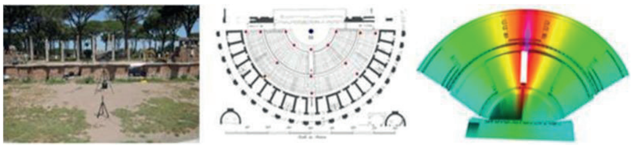


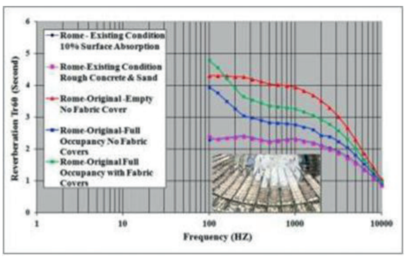
Fig. 6 - Ostia Theater site sound distribution and auralization in a virtual environment.

Acceptable sight lines toward the center of arena within the Roman Coliseum and the stage within the Ostia Theater are provided for viewers to experience the space in a VR environment. The symbolic frontal stage design and seating areas as part of the historical settings allow for the careful examination of the acoustic characteristics as auralized and recreated virtually within these sites for an audience. Various acoustic conditions can be listened to without the distraction of elaborate, full mock ups of architectural sets at the site which accommodate the comfort of tourists and casual viewers. The interactive possibilities within VR environment as reconstructed for various cultural heritage sites offers opportunity to experience objects and key historical and architectural elements (e.g.; digital rendering of physical objects surrounded with rich sets of contextual information that can inform, suggest analogies from other experiences, and stimulate thinking on related topics such as color of paintings, sound of crowd (see Figure 7) or a musical instrument or event).

RESULTS

The basic principles of acoustics of ancient theaters are well known but are not as easy to use them as part of an architectural and functional recovery, because of the different states of preservation and found changes that these structures may have suffered over the centuries. The evaluation of acoustic quality can be made with different methods [4]; physical

Fig. 7 - Simulated sounds propagated within the Roman Coliseum, for representation of the historical records on shading system and their impact on crowd noise within the reconstructed virtual environment. Red = Original design without the crowd noise and Green = shows the impact of the shading system on reverberation and noise reuction. and auralization in a virtual environment.



acoustics, physical scale models, diagnostic tools and numerical models. The standard approach involves analysis of the impulse response of the environment, obtained experimentally or numerically.
Richer educational experiences are possible with multisensory input (visual, auditory, avatar movement of curtain, daylight and an accurate change of colors due to inter-reflection and interaction with the object) to help foster a sense of place within a synthetic historical context. The on-site measured surface luminance, chromaticity and spectral data were used as input to an established real-time indirect illumination and a physically based algorithms to produce the best approximation for RGB to be used as an input to generate the image of the objects. Conversion of RGB to and from spectra has been a major undertaking in order to match the infinite number of spectra to create the same colors that were defined by RGB in the program [6]. See Figure 8.
The Rector's Palace - Sponza Palace in Dubrovnik atrium space simulated space conveys an interior space with or without daylight, which suggests a disciplined perspective with the placement of room artifacts and attention to its building historical elements in detail.

Fig. 8 Dynamic movement of a red curtain simulated (left) while measuring SPD in real time (center) and luminance distribution changes due to inter-reflection of light on the wall is shown at right. The blue and red lines within SPD plot shows closed and open curtain setting with peak contribution in red part of the spectrum.

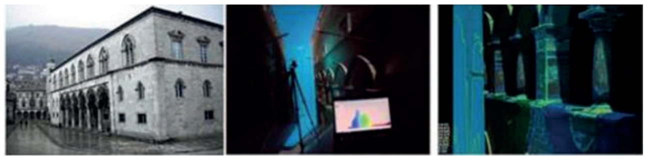


Fig. 9 - Reconstruction of the Rector's Palace - Sponza Palace in Dubrovnik atrium space as simulated within the CAVE and real time measured SPD and luminance distribution of blue reflected light within the animated scene with Curtin's movement.

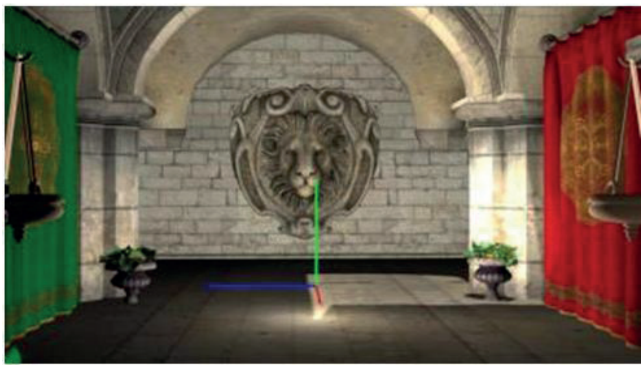


Fig. 10 - Reconstruction of the Sponza Palace room interior artifacts such as sculpture.

A higher information or stimuli load is considered with the current geometry of these elements and the incoming daylight through the atrium space. The space also suggests an environmental psychology principle of how viewers can be situated in a space for viewing the light and dark areas of artworks (e.g., hung fabric materials) under different lighting conditions while being considered for its preservation.

Figures 9-12 show that the banner surface reflects light in the blue regions of the spectrum as measured with spectrometers including the simulated color distortion due to reflected component impacting color of banners and their walls detail textures.

ANALYSIS AND DISCUSSION

The use of computer generated images within CAVE could be an alternative to the use of real or full mocked up space during the design concept or historical building evaluation. In the Figures 8, a red curtain was illuminated by sunlight being simulated as a point source spotlights at 30 degree elevation or not perpendicular to the wall. The light bouncing off the red curtain while being animated within the VR scene created a red gradient on the white walls. The color signal of the bouncing red curtain was measured. This particular capability was also simulated in scenes (Figure 9-12) utilizing an algorithm for visualization, including real-time shadows and massive lighting, a rendering engine that implements algorithms published by Anton Kaplanyan [21] and others developed in-house, taking advantage of modern graphics hardware with GLSL shader programs [22]. VR is no longer being viewed as an entertainment system but now is being used in scientific investigation for its visualization capabilities. Although, there are unique applications in which the design objectives demand high accuracy in simulated results, this method may not require absolute accuracy, in order to accelerate the decision making process. The information provided by these results and analysis could outline a set of future guidelines or requirements for simulation requiring high accuracy within a given dynamic range of spectrum [8-10]. The viewing and exploring of cultural heritage buildings is examined through the application of an immersive virtual reality environment that is proving to be a well suited platform for scientific and educational experimentation, exploration, evaluation and propositional test and evaluation trials.

The examples presented in this article describe the use of the 3D virtual reality laboratory. This highly innovative and interactive technology offers users across many disciplines opportunities to enhance traditional instructional methodologies. The technology provides a close fit between immersive virtual worlds. This takes advantage of how users prefer to learn and interact within and across areas of science associated to preservation of cultural heritage buildings. Immersive virtual reality learning environments can be designed to be experiential and intuitive. They provide learners with control over time, scale, and physics for a shared experience and information supporting interactive simulations, concept visualization, and observation from many perspectives. Examples of immersive virtual reality constructed for these selected sites are used for assessing their building environmental boundary conditions such as the impact of sound and light on the interiors of buildings and their sites [23-25].

CONCLUSIONS

Application of virtual reality technology for sound and color perception is achieved through auralization and visualization of interior as well as exterior of historical buildings. The real time recording, monitoring and simulation procedures used for these spaces' existing conditions could be applied to evaluate real or virtual settings of historical buildings. Results of 3D digital scanning devices combined with accurate measured color and spectral reflectance of real surface materials allow conversion of reality into digital form in a cost and effective way to be presented and used for public engagement and educating future generation of

Fig. 11 - Reconstruction of Sponza fabrics with specific interior fabric with texture.

Fig. 12 - Interior Sponza surfaces as simulated for color distortion due to reflected components
http://www.dubrovnikcity.com/dubrovnik/attractions/rectors_palace.htm

preservationist as cultural heritage certified accredited professionals. This immersion capability allows stimulation of all human sensory subsystems in a natural way within this virtual environment.

Representation of historical buildings in form of realistic computer reconstructions allows general public engagement and discussion with specialist regarding the true perception of the past environment and interpretations of theoretical issues associated with the use of spaces in a given historical period. Immersive virtual environments for audio and visual sensation provide much richer and perceptually realistic methods of exploration and investigation for cultural heritage building. The application of such methods allows various scenes in combination with wide-spread real-time rendering techniques for light and sound to be utilized for viewing and experiencing historical heritage types of buildings under investigation. The collected results are used as archival records and might be a promising research direction. Future wireless physiological/neurological monitoring in the CAVE offers a great opportunity for unobtrusively quantifying of human response and interactions (conscious or subconsciously) in a simulated environment to a precisely controlled and readily modulated virtual environment representation various interpretation of past living or working environments.

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ABSTRACT

These paper present accurate reconstructions and virtual representations of buildings of cultural heritage, which have been developed techniques of visualization and auralization in virtual environment. Computer graphics allows to reconstruct and experience the visual and acoustic conditions of the past with a high degree of realism and to deepen the knowledge of cultural heritage.

KEYWORDS

ARCHAEOLOGY; GLOBAL ILLUMINATION; VISUAL PERCEPTION; BEAMFORMING; ACOUSTIC MAPPING; VISUALIZATION; SOUND LOCALIZATION; AUDITORY NAVIGATION; VIRTUAL ACOUSTICS; SPATIAL HEARING; DYNAMIC AURALIZATION;

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