Collaborative Design in Virtual Space - GreenSpace II: A Shared Environment for Architectural Design Review

James N. Davidson, AIA
Dace A. Campbell

Department of Architecture & The Human Interface Technology Laboratory,
University of Washington

ABSTRACT

Design reviews and discussions are fundamental to the process of design. The ability to digitally represent three-dimensional space in real-time is a new and potentially persuasive method for reviewing and analyzing a design proposal. The development of real-time rendering engines and network protocols supporting distributed interaction makes possible the idea of a shared virtual environment for architectural collaboration. This paper presents a system which facilitates the review of an architectural design between multiple participants who are remotely distributed.

DESIGN COLLABORATION

Collaboration is fundamental to the design process. No significant architectural design is ever realized by a single mind: a project where the designer is also the client, the contractor, and the tradesman is extremely rare. Even the most rudimentary project requires an interaction between multiple minds. These relationships exist to facilitate the communication and then the iterative refinement of the design idea. The cycle of, communicating, analyzing and critiquing, idea, and then the re-documentation of the idea is the essence of the design process.

In the academic realm the collaborative setting is the desk crit, or the design jury. In the professional setting the corollary to a desk crit is a senior designer reviewing the work of a subordinate; the jury is analogous to a client presentation. In each of these cases the collaborators rely heavily on the visualization of a design proposal presented by drawings and models. This project focuses on the social settings and process involved in the communication and critique of a design proposal using distributed virtual environments. Our work demonstrates the use of a shared virtual environment as a tool for architectural design review.


A procedural model for the process of design involves three steps: First, the generation of a design idea. Second, the documentation, representation or simulation of that idea. Finally, the dissemination or communication of that idea in some medium followed by a critique and refinement of the idea. This is of course a reiterative process which is continually taking place on many levels (Wojtowicz, Davidson & Mitchell 89-90).

In a typical design review setting, the collaborators do not work together to "create" or "construct" some new design, rather they communicate between each other the ideas which are part of a pre-existing design, and then they analyze and critique the design. "Graphic invention is not to be confused with graphic communication. The former is a formative process concerned with the conceiving and nurturing of ideas; the latter is an explanatory process concerned with presenting fully formed ideas to others" (McKim 40).

The essence of design collaboration then, is the communication, sharing and refinement of design ideas; this is the third step in our procedural model. In a collaborative relationship the individual participants may engage in a great deal of idea generation and documentation, but these are generally solitary tasks. As Gropius characterized, "...there is no doubt that the creative spark always originates with the individual" (Gropius Apollo 53). Pure design is not a collaborative task.

Typically in architecture the design idea, or information, resides in the drawing, and it is expressed and well documented in physical models. With digital media the idea ultimately resides in a database which can be presented in the form of a drawing or three-dimensional model: the medium is the vehicle for collaboration. For a design
review to take place, a pre-mediated idea must exist (i.e. a drawing or graphic) to be the focus of discussion. The GreenSpace project is based on the premise that with simulation technology the design idea is documented digitally and can be presented in real time to support design collaboration.

Characteristics of the Design Review:

- Design reviews generally have a single person taking the floor, and speaking while the others follow the presentation.
- Design reviews are heavily influenced by the tradition of pinning up drawings.
- Participants in a design review are able to view many graphics at one time without losing the sense of who has verbal control.
- Design reviews generally have less than twenty participants.
- Collaborators do not create entirely new drawings or models during a design review; verbal critiques are commonly supported by simple sketches.
- A new original design idea can be verbalized during a design review, but it cannot be documented in any detail, only as a sketch.

CONTEXT: DISTRIBUTED SHARED ENVIRONMENTS, GREENSPACE I AND THE VIRTUAL DESIGN STUDIO PROJECT

DIS Systems

Historically, a number of systems have been implemented for collaborative work in a virtual environment. Early systems of this nature were used in military applications. These shared environments were used to train military personnel for particular tasks or for action in a particular geographic location. The first such system was sponsored by the Defense Advanced Research Projects Agency and referred to as the SIMNET (SIMulation NETwork) program. Subsequent research and systems of this type, where many participants share an environment via a networked simulation, are called Distributed Interactive Simulations (DIS) [citation forthcoming]. In addition to the research and work done for military applications, there have been a number of non-military research projects using this type of technology, one of which is the GreenSpace project, conducted by the Human Interface Technology Lab (HIT Lab) at the University of Washington.

GreenSpace I

The goals of the GreenSpace project are to develop and demonstrate an immersive communication medium where distant participants feel a sense of presence in a shared virtual environment, a “virtual common”. Ultimately, the project aims to promote collaboration at a distance among many participants immersed in a rich environment. An historical demonstration of this technology took place in November 15-18, 1994 (Mandeville 1995). In this system, collaborators entered a shared virtual environment and sat around a table where they were able to see, hear and interact with colleagues across the Pacific Ocean. In a collaborative effort, two participants in Seattle, Washington and two participants attending the NICOGRAPH conference in Tokyo, Japan could work together to “herd” artificial creatures into a “corral”. Each participant received visual feedback through a Head Mounted Display (HMD) while their head and hand were tracked and rendered in the environment.

Virtual Design Studio

There is a large body of research in the area of distributed collaborative work. Generally these efforts have not concerned themselves with real time interaction, as in the SIMNET. One such effort in the discipline of architectural education is the Virtual Design Studio (VDS) (see Wojcicki, Davidson and Nagaskar “Digital Pinup Board” 9).
The VDS projects (Figure 1) are based on the premise that spatially distributed design collaboration can and will take place using digital media. These projects have focused on the notion of asynchronous design, which is one type of collaborative work based on the parameters of space and time.

A collaborative effort can take place in one location or in many... at the same time or at different times. One of the four different combinations of these two binary variables of space and time is the traditional 'face-to-face' collaboration where participants work together at the same time and place.

If... face-to-face collaboration is the least technology-intensive type of interaction, the distributed synchronous collaborative effort is its opposite in the sense that it requires high-tech solutions to have people working together in real time while in different locations (Wojtowicz et al., "Aspects"

With the continuing advance of real-time simulation technologies, it is feasible to consider the use of shared virtual environments as part of a synchronous collaborative design endeavor. The intention of the second phase of the GreenSpace project has been to direct the functionality of shared virtual environments towards a particular application domain. Building upon the work of GreenSpace I and the Virtual Design Studio projects, GreenSpace II (GS2) has introduced a system for collaborative design in virtual space.

GREENSPACE II: CONTENT, IMPLEMENTATION, AND FUNCTIONALITY

Content for GS2

Architectural program. For this project, a restricted design program was chosen: the design of a hotel guest room. This program was chosen because a hotel guest room allows for a variation in content and spatial qualities without complex geometric models. Also, a pre-existing model had been built by the HIT Lab as a result of a research project conducted in association with Westin Hotels and Resorts. In conjunction with the Westin guest room model, two alternative rooms were designed and built by students and faculty of the College of Architecture and Urban Planning (CAUP). These three schemes were identified as guest rooms "A", "B", and "C" (Figures 2, 3, & 4).

To provide an architectural and a virtual context for the rooms, two other spaces were created. A hallway was constructed in order to access the three alternate guest rooms. At one end of this hall a virtual vestibule was placed. This vestibule is intended to be a spatial interface to this content as well as other virtual environments (Figure 5). This vestibule is an implementation of the idea that a spatial desktop is needed for accessing three dimensional spaces and applications, similar to the common desktop metaphor of the Macintosh and Windows computer systems.

Content. Each of the three room alternatives were represented by multiple versions. A mechanism for additional permutations of each was initiated. This was intended to allow the virtual critics to view the space in different modes. The basic versions of each room were: the bare geometry with no textures; the unfurnished room, with textures representing a particular lighting solution; and a furnished textured scheme. A simplified room model was reduced to a scale of 1:20 and placed on a worktable to facilitate the plan/section tools. This forms the core content of the GreenSpace II environment: three alternative designs for a hotel guest room simulated with varying degrees of detail (Figures 6, 7, & 8).

Content construction techniques. Construction of the architectural models for GreenSpace II involved several applications and platforms. The principle geometry was created in AutoCAD and exported via .dxf into Lightscape and 3D Studio. Lightscape was used to generate a radiosity solution from which orthographic images of each room surface were created as bitmaps. These bitmaps were then applied as texture maps in 3D Studio. The .dxf file was converted into Inventor and subsequently simulated using the GreenSpace application (GSApp).

GS2 Functions

To facilitate the review of design content and to enable collaborative interaction within the GS2 environment, a number of functions and tools were implemented. Some of the functionality was global and available at all times while other tools were localized and facilitated by a "worktable" which was present in each version of the
three guest rooms (Figure 9). All of the GS2 functions fall under three categories: navigation, communication and manipulation.

**Navigation.** The navigation functions are of two types: intra- and inter-environment navigation. Intra-environment navigation is the ability for each participant to move with six degrees of freedom within a particular model or world, independently. Inter-environment navigation is the ability for a participant to move between different worlds or environments, or in the technical sense, between separate files. Two types of hyperlinks are used for inter-environment navigation: door- portals and jump- ports.

Door-ports are used where spatially contiguous files needed to be linked. This designation is typified by the arrangement where a portal between the corridor model was linked to a particular room model via the architectural feature of a door opening, hence the name.

Jump-ports are links which are associated with an object or image where the current environment and the destination environment do not have a direct geometric spatial relationship. This type of portal is accessed with five box icons located next to each scaled guest room model, on the worktable. By selecting one of the icons, and then activating the "transport" command, a participant is transported to that destination model. Two of the icons are boxes representing the room version with bare geometry and no textures, and the unfinished room with textures. The other three icons contain a small cube and represent a different furnished textured version of the room. Each of the box icons are color-coded for visual reference (Figure 10). In addition to the proactive door and jump-ports, two commands were created to assist in navigating: a "back" command and a "home" command. The back command returns the participant to the previous world visited via a link, and the home command returns to a default camera location.

**Communication.** The ability to communicate with one's collaborators is crucial to the interaction which takes place during a design review. Verbal communication is a necessary condition for collaboration, but it is not sufficient. Design reviews require graphic and gestural aids. To support verbal communication, a network audio system was used, running over the local Ethernet network. This was generally adequate for the three participant workstations in these demonstration reviews. For visual communication, each participant is represented in the environment by a stylized head and hand pointer. Each avatar has a color - red, green or blue - to give a unique identity to each participant (Figure 5). The avatar's head and hand can be manipulated together or independently. The hand pointer is seen as a critical element for graphic communication: designers are very gestural as well as graphic. The ability to direct a colleague's attention to a particular element of the design through pointing and gesturing is extremely important for communication.

For designers, the ability to inhabit a digital representation of an architectural proposal in real time is a provocative and powerful tool. However, in specifying the needed tools for the application domain of a virtual design review, it became very clear that a method of displaying the plans and sections of the design under discussion was a necessity. As powerful as virtual reality is, the traditional graphic conventions of abstracting a space into plans and sections remain critical in the design process. In this light, we investigated a number of techniques to display the plan and section, and designed a clipping tool to enable this. Each of the scale models located on the worktable has a wire-frame bounding box surrounding the extents of the model. This bounding box delineates a clipping volume which "cuts" a plan or a section when moved through the associated scale model. By selecting the bounding box with one's pointer and activating the "move" command, a participant can generate a plan or section as desired (Figure 9). Once a satisfactory cut is accomplished, the "done" command is activated and the model remains "clipped" to show a plan or section. With this technique a participant can point and gesture at relevant items in the model, cut as a plan or section for the other participants to view.

**Manipulation.** Finally, in addition to the navigation and communication functions two commands were created to allow for limited manipulation of the environment. Other manipulative tool sets were considered. However, with the focus being the design review, where little actual design creation takes place, a minimal number of tools were implemented: the "move" and "color" command.

The "move" command is the same as that used to move the clipping box for the plan and section tool. For the demonstrations, certain pieces of furniture were designated as movable objects and could be selected and moved about the guest rooms. Somewhat different from the clipping box, these objects are restricted to movement along the floor in the x, y plane (Figure 11).

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The final tool implemented is the "color" tool. After selecting an object, a participant can activate the color command, which displays a color cube for that person only. The surface of the cube is rendered with a gradient of colors shaded from vertex to vertex. By touching the surface of the cube with the hand pointer the selected object takes on the color of the cube at that point. With this simple device any editable object in the environment can be re-colored (Figure 12).

GS2 User Interface

A major goal of the GreenSpace project is to have scalability in platform support, as well as in numbers of participants. This implies that different critics will have either an on-screen interface or an immersive interface to the shared environment. The current implementation includes both of these interfaces.

For both immersive and non-immersive stations, intra-environmental navigation is supported by a six degree of freedom input device. For the demonstration reviews, these devices were Logitech Cyberman joy-sticks. In the immersive set-up, visual display is provided by a VR4 Head Mounted Display, while on-screen display is provided by a graphics window rendering the camera view from the head position of the participant. In the immersive configuration, the participant's head and hand are tracked using a Polhemus FASTRAK. This permits the immersed participant to not only move his entire body via the Cyberman, but also to independently move his hand and head.

For the on-screen participant, normal movement of the Cyberman translates and rotates both the participant's head and hand in 3D space. A button on the Cyberman is configured to allow the participant to move the hand pointer independent of the head position. This gives the on-screen participant the ability to freely move about the design content, and to "reach out" and gesture to particular aspects of the model, as well as make selections for object manipulation.

GS2 System Description

For the demonstration reviews conducted thus far, the system has been configured with three possible workstations. One immersive workstation (SGI Onyx RE2), and two on-screen workstations (an SGI Indigo2 Extreme, and an SGI VGX Challenge series computer). The sound system runs parallel to the visualization machines on three Digital Alpha workstations. GreenSpace commands (GSC commands) run native on the on-screen workstations, and on a Windows95 based PC for the immersive station.

Format of Experimental Design Reviews

During March of 1996, a series of demonstration and experimental design reviews were held. These review sessions were held in order to expose design faculty and professionals to the features of the system and to solicit their feedback. This was done to refine the specifications of the GreenSpace application and to prioritize future development of the system. To date, approximately fifteen design professionals and academics have used the system.

The general format of the demonstration proceeded as follows. First, the invited critics were briefed on the architectural program, the three proposed alternatives, and the general layout of the content. With research staff operating the system, the critics were shown the functionality of the application from the view point of the immersive participant. All demonstrations began with the three participants meeting in the virtual vestibule. From the vestibule, the participants navigated down the hall and entered one of the rooms through a door portal. In this first room, which was the textured unfinished version of Room C, the critics were shown the worktable and the plan/section cutting tool. Using the box icons present on the table, the demonstrators used the jump portal to transport into the furnished version of Room B. Once in Room B the visitors were shown the move and color commands. Following this introduction to the content and the functionality, the visiting critics were invited to take control of the immersive station and one of the on-screen stations. They were encouraged to become familiar with the navigational device and the tool set, and after some time, were invited to engage the other participants in a dialogue regarding the architectural content and to provide feedback regarding the system.

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LESSONS LEARNED AND FUTURE WORK

This project has demonstrated the potential for distributed synchronous design collaboration in the focused setting of a design review. However, these demonstration reviews are too limited to draw complete conclusions from this research effort. In terms of design, there are two significant limitations of the reviews to date. First, the content created has not being presented by the authors of the work. The presentation of the content was made in the abstract, as opposed to the designer describing his intentions.

Secondly, the invited critics have not had sufficient exposure to the interface to be comfortable with the navigation and communication techniques. Ultimately, you want the interface to become transparent. However, new users were overwhelmed by the interface and were just getting comfortable with the system after using it for about 30 minutes. To expect a substantive discussion to take place over a new medium during one’s first exposure is overly optimistic. Familiarity with a medium is necessary for the message to take on some degree of meaning.

Observations

Design observations:

- The architectural program was too simple to effectively demonstrate the complete usefulness of the plan/section tool. However, during some of the demonstration sessions the plan/section tool proved very effective in orienting the critic to the layout of the room and his current position.
- Only a small number of objects were movable. In a furnished solution all/most of the furniture should be movable.
- The color tool was not available for all objects. This function should be available at all times.

Technical/Interface Observations:

- The plan/section tools, although useful, are in a fixed location. A better implementation would be to have the tools available at all times.
- The content creation procedures were labor and expertise intensive. In order to have a high visual quality simulation, it is important to have models that display variations in light and shadow which are close approximations to a real lighting solution. Models experienced in real time which only render flat shaded geometry are much less convincing as an inhabitable space.
- Navigation with full six degrees of freedom is disorienting at times. A method to restricting one’s navigation to the x, y axis at some default eye height is desirable. Having the ability to turn on all degrees of freedom when desired would be useful.
- The vestibule was intended to be a personal 3D interface to a global virtual space, such as the World Wide Web. It was not implemented in this fashion, and so cannot be evaluated on this point.

Social observations:

- The demonstrations were scripted to introduce the visitors to the content via the vestibule. This neutral gathering space was socially very effective in providing participants a location to “get acquainted”.
- Social communication appears to be more dependent on sound than video. (Is this a function of telephone culture and literacy?) When the audio signal was inconsistent or unclear, it was not possible for the participants to establish an effective social dialogue.
- The audio signal was not spatialized. It is assumed that this would help with way finding and social interaction.
- The disembodied head/neck bothered a few participants, but most overlooked it, accepting the other person as “the green avatar” and focused on other things.
- The presence of another avatar/person in the shared environment is very social. When another avatar was not visible, a sense of longing was identified. It was uncomfortable to have the avatar move out of one’s field of view.
- It is important for participants to know if other participants are in the space, and where. A roving map which can travel with you and orients you in plan is desirable.

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Guest critic and reviewer comments:

- "I realized [after the review] that I didn't do what you asked me to do, which was to review the hotel design project. And I realized why: as you indicated, I was too busy getting used to navigating through the room (namely, trying not to float through the ceiling!) to settle down and give a crit."
- "I noticed that [the young student] more used to these tools than I am, headed right for the section tool, which I avoided, figuring I didn't have the "dexterity" to even "hit" it!"
- "It was...unerving to hear my voice echoing back over the audio system, and I must admit that it made me self-conscious."
- "It's also much different "criticizing" a professional...than a group of students; subtle, but real, psychological relationships." [This guest critic attended a session with one of the designers of the Westin guest room. Ed.]
- "...the view of the room that I got from my 'head' was not so wide that I could easily encompass the whole room."
- "I think it would be easier with just two people on different computers 'talking' to each other. It's more awkward with an audience."
- "One of the interesting features in the room was the proposed glazing. Would it be possible to include data on it somehow, both visually and numerically (i.e. as to performance)?"
- "The field of view on the CRT is too small to get a sense of the space." [The field of view can be adjusted in the GS2. This reviewer experienced a 45 degree FOV. Ed.]
- "Roll of image was distracting. Would be nice to reset view to eye height and orientation when desired."

Future Work

In the future, it will be important for critics to be able to use such a system routinely so that the attention is shifted to the dialogue concerning the content rather than the mode of communication. In the short term, it is intended that a larger body of designers will have repeated exposure to the GS2 system to continue to refine the functionality and to determine the suitability of the technology as a facilitator for remote collaboration.

Although this phase of our work was implemented on site at the HIT Lab, the GreenSpace application supports geographically distributed shared spaces. It is planned that an implementation of GS2 will take place between the HIT Lab and one of the VDS participating schools. It is clear that the use of digital media for design provides powerful new tools for collaborative work. As these new tools are built and specified, they will be most successful as they accommodate conventional design metaphors and vocabulary, while at the same time supplanting the particular limitations of paper media.

CONCLUSIONS AND SUMMARY

Design collaboration primarily involves the communication of design ideas, and the critique of these ideas. The culmination of any architectural design idea is the realization of the built work itself. The drawings and models are merely abstractions of that final realization. Virtual interfaces and real-time simulations present a fundamentally new kind of tool for communicating and critiquing design intentions. This project recognizes the power of the new media while accommodating the continued use of abstract representation of scale models and orthographic projection drawings.

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Figure 1. VDS Home page

Figure 2. View of room A.
Figure 3. View of room B.

Figure 4. View of room C.
Figure 5. View of Avatars greeting within the Vestibule.

Figure 6. View of room B no textures.
Figure 7. View of room B with textures.

Figure 8. View of room B furnished with textures.
Figure 9. View of worktable with plan and section tools.

Figure 10. View of worktable with jump-portal box icons.
Figure 11. View of Avatars moving chair.

Figure 12. View of Avatars changing the chair color.
APPENDIX

Content Construction Techniques

The specifics of our content construction procedures are as follows:

Geometry and Nomenclature.

In AutoCAD a layer/object naming strategy was initiate. Although different applications use the alternate names of layer and object to refer to geometry and file hierarchy, for the purposes of this paper we will use the term object. Each wall, ceiling and floor surface for each principle space within each guest room was given a unique object name. The object nomenclature was based on five unique criteria: guest room; space/room number; surface type; orientation; numerical identifier. For example, this created object names such as, "001WE01", which would identify: guest room "8B"; space/room number "01"; surface type "W" (for wall); wall with an East orientation, "E"; and eastern wall surface number "01". For floor and ceiling surfaces the orientation designator was dropped. This naming convention was critical to maintain control over the geometric database as it moved through the different applications, and also to facilitate the matching of unique texture maps to the appropriate geometry.

Radiosity Processing

Once the core geometry was constructed, a .dxf file was created in AutoCAD. This .dxf file was then imported into Lightscape on a Silicon Graphics workstation (SGI). In Lightscape, the normals of all polygons were checked and flipped as necessary. A default material map was applied to all the objects, assuming typical room finish materials. Lights were defined either by defining blocks which existed in the source file as luminaries, or by adding luminaries from a library. After the geometry, materials, and lights were defined, a radiosity solution was calculated. To make rendering times more efficient, and to reduce the size of the radiosity mesh, specific surfaces (such as furniture) were specified not to generate any mesh. The geometric representation of the furniture was then used within Lightscape only to produce shadows on the floor and wall surfaces.

TextureMap Creation

After an acceptable radiosity solution had been calculated, a bit map was created depicting each unique rendered object. This was done by turning the display of all objects off, except one specific surface. A strict orthographic view of the object, or surface, was defined and an image of that object was saved to disk. These images were saved at a high resolution in an .rgb format with a file name which matched the object displayed. These .rgb bitmaps were then cropped and sampled down to a maximum resolution of 256x256, using XV running on an SGI. This process produced an average of 15-20 bitmaps for each guest room model. These bitmaps were then translated into .gif and .tif format. The .tif files were transferred to a Macintosh where they were further edited in Photoshop to clean up edges and other blemishes. They were then transferred back to the SGI platform and returned to the .rgb format, ready for simulation. The .gif files were sent to a PC for use as texture maps.

Material Definition and Mapping

CoordinatesParallel to working with the .dxf from AutoCAD in Lightscape, the same source geometry was imported into 3D Studio. In 3D Studio the bitmaps, created in Lightscape and saved as .gif files, were used to create a library of materials with a unique material defined and named to match each object. Certain objects in the models, like the furniture, did not receive a radiosity texture map. These objects were given a simple RGB color definition. Once all the materials were properly assigned and the correct mapping coordinates were applied, the .d3s file was ready for rendering in the Unix environment.

Conversion and Editing of Open Inventor Files

The .d3s files were then converted into Open Inventor using SGI's 3dsToIv utility. At this point the .iv version of the .d3s file could be checked using iview. If there were problems with the geometry, or the textures, they could be evaluated in IVVIEW and the appropriate corrective steps outlined. Most of the models went through a number of iterations of this process: editing the geometry, generating radiosity textures, assigning the textures, and then running a test simulation. For the two textured versions of the individual guest rooms, furnished and un-
furnished, this process was repeated to construct a unique model and an associated family of texture maps. Once an acceptable 3D file was created, the file was then edited to define hyperlinks and tool functionality.

The Inventor files for each guest room included two parts: the static environment and detectable or editable objects. Detectable objects included those sensitive to the participant’s head position and those sensitive to the hand position. Door-portsals are activated by the head, while jump-portsals, the plan/section tool, and movable objects are selected by the participant’s hand. All objects specified as detectable were modified using IVTX, which created an IndexTriangleScript of all geometry. This was necessary for collision detection to work for those specific objects. Once these objects were "fixed" they were edited back into the appropriate file using basic cut and paste techniques. Also, a ShapedHints node was added so that both faces were rendered regardless of the viewer’s station point. This was done so that orientation of geometry normals was not a concern during construction. As well, a DECAL field was added at each texture node, so that the true pixel value of the textures was rendered independent of the RGB value of the surface on which the texture was mapped.

REFERENCES


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