On Developing Standards for the Creation of VR City Models

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The paper is an inclusive summary of research work on creating VR city models carried out over the last six years in the UK and Greece aiming to put into discussion the guidelines/ rules developed by the author.
The paper is structured in three sections referring to the main stages in terms of either technical expertise and problem solving or conceptual structuring of information: creation of 3D city models, CAAD versus VR in digital city modelling and finally utilizing digital city models.
The expected outcome of the work presented is the establishment of a body of knowledge that will facilitate the development of standards and guidelines for the creation of city models. There are obvious advantages in having a compatible set of city 3D models. On the other hand, there are different rules to be followed and issues to be solved, according to the scale of the model, level of detail that is needed—all these rules relate to the projected use of the model.
Keywords: *digital city models, 3D modelling, virtual reality, urban planning*

Background

Architectural and urban design is full of assumptions and conventions to an extent not applicable to many other disciplines. This has always been the case with paper based drawings considering the fact that 3D information, the urban structure, had to be expressed and communicated on a 2D medium, the drawing. This approach has worked quite well with paper drawings since professionals are trained to read drawings quickly and with minimum effort, though average performance is obtained using a computer. The main reason being that one has to decide and either imitate the paper based approach and thus do everything in 2D or advance to 3D modelling. Opting for the second means that a new set of rules and conventions have to be invented/developed together with an even better understanding of 3D space. In creating a fully 3D interactive Virtual Reality (VR) application, due to lack of architectural / urban planning experience in the field—with the exception of work carried out in the UCLA Urban Simulation Team AUD (Jepson et al, 1996), ART+COM (www.artcom.de/contacts/city-and-architecture/ welcome.en.old.shtml:May, 2001) and others—VR conventions and methodologies are adopted. Furthermore, a close examination of the techniques the above mentioned groups use, reveals that VR methodologies are taken for granted and therefore carefully tuned and appropriately built models are employed rather than custom tools for urban scale modelling being developed.

In this paper, the author draws from the experience obtained in constructing the VRML models of Bath city, and London's West End together with the work he is currently involved in Volos, Greece to develop a set of standards for the creation of CAAD urban models and, mainly, their conversion to VR models. Due to the nature of the topic and the size limitation of the paper, the work carried out so far by the author is not analytically documented. It is recommended to refer to a series of papers by the author addressing VR city modelling in depth. Most papers are also available online (fos.prd.uth.gr/vas/papers/:May 2001)

Creating 3D digital city models

The starting point for any digital model is the data source. At an urban level, source could be the existing 2D city plans and stereo pair aerial photographs, bearing in mind that most 2D city plans are based on photogrammetric data. However it is recommended that, in order to have maximum compatibility with existing city plans, creating the whole 3D model from scratch should be avoided. Established work in terms of defining the 2D data for each properly, element in general is not replicated thus model construction is a hybrid one using existing plan data and aerial photographs for the extraction of the elevation information of the buildings, height of trees, chimneys, roof geometry information, dormer windows etc. Furthermore, discrepancies on plan data are avoided simplifying the job of engineers that may use these 3D datasets at a later stage.

Choosing the appropriate software platform is essential. Using a widely available commercial software platform warranties compatibility, ease of access to prime data source and conversion to other data formats. Depending on the projected use of the model, in-house tools may be needed. However, care should be taken in order to be able to export the geometry to one of the widely accepted formats namely Data Exchange Format (DXF) and Virtual Reality Modelling Language (VRML). Similarly, the software used should be compatible with data obtained from foreign sources–engineers working on a particular project within the area modelled, modular data created elsewhere, etc.

The next issue that has to be tackled is that of the level of abstraction in modelling. CAAD operators and 2D modellers in general tend to over-design, model in deep detail, usually irrelevant for a VR application. This well established trend must be avoided. The only solution is prototyping a representative area of the proposed model, converting to the final VR environment and testing before establishing the detail level rules.

Data source scale and projected use are also important in establishing the accuracy level of the model. 2D source data should be at a scale close to 1:1000 and definitely better than 1:5000 if the resulting model is to be of an accuracy level of less than half a metre and close to twenty centimetres. The aerial photographs scale is vital at achieving a high level of detail and should be close to 1:3000–anything over that results in 3D models with an accuracy of more than a metre a value unacceptable for planning oriented city models, but may well be suited for other applications.

City models are continuous geometrical constructs expanding over kilometres in length and width. It is not practical to work on such a project unless a subdivision strategy for the digital model is employed. The aim of such a subdivision is twofold; to be able to store the source data in manageable sized files and to enable engineering professionals obtain the needed parts of the city in order to base their work on a well-established dataset and keep the main 3D database of the city up to date. The most appropriate subdivision unit is that of an urban block furthermore simplifying naming conventions by following the current urban block numbering system.

Making the step from CAAD to VR in city modelling

Moving from a CAAD 3D model to a VR application involves the complex stage of data conversion. Issues common to all VR applications will be analysed.

Urban models are very often constructed using the country's unit origin in metres. For example in the UK, Ordnance Survey origin is used; that is Lands End, Cornwall the most south-western tip of Britain. CAAD software have no problems dealing with large numbers (a typical city modelled maybe a million units away from origin point) or with the units; a metre with three decimal points. However, VR applications often use integer mathematics for certain geometric calculations. This leads to a series of rounding errors and great problems with Z buffering. Furthermore, trying to rotate or spin the model is impossible since browsers rotate about the co-ordinate origin; 0,0,0. All navigation, rotation, and most Z buffering problems are solved once the origin point is translated to the centre of the urban model. A side effect is the file size reduction since all numbers dealt with are much smaller.

CAAD software use a world based co-ordinate system; X and Y for the plane definition and Z for elevation. VR software typically utilise a screen based co-ordinate system–X and Y across the computer screen and Z out of the screen. This effectively means that Y and Z have to be swapped from a CAAD model to a VR. Depending on the CAAD software, the output VR format, and the process followed, this is dealt with varying degrees of competence and correctness. Sometimes the conversion process introduces transformation matrices making the VR output file difficult, if not impossible, to comprehend and edit manually. Failing to exchange the Y and Z results in models that cannot be “walked” through, since the viewer-perceived walking is carried in X and Z meaning the viewer comes flying from the sky to the ground.

A serious problem of model translations is the structure of the geometrical description itself. In most CAAD packages, the operator can define surfaces that are perceived as double sided. Indeed, the standard on hand modelling surfaces is double sided. This means, considering three points in 3D space, the surface defined by triangle (A, B, C) is the same as the one by triangle (A, C, B). VR applications usually define surfaces as being single sided and anticlockwise. Some renders have the option of rendering double sided faces - at the penalty of a considerable speed reduction usually by a factor of two.

Having converted the dataset the success of a VR application is judged by the degree of geometry optimisation achieved.

VR applications have a fairly clearly defined upper limit of amount of geometry they can handle successfully which is quite low and unsuitable for urban scale modelling. In general, software developers and VR designers/artists recommend replacing geometry with simplified repetitive texture mapped shapes. However, this approach can only be successfully implemented in certain types of models and it seems to be producing acceptable results in American towns, skyscraper filled city centres high-rise office blocks and generally highly repetitive environments. As an example, the author in the process of converting the CAAD model of Bath in VR, classified the existing types of properties, roof geometry, and other urban entities in a list of over 200 elements (Bourdakis, 1996). Bearing in mind the generalisations that took place in creating this “restricted” list, the projected utilisation of the model and the inevitable downgrading of the available data, it was decided to discard this approach. Repetitive elements indeed exist in urban scale models but due to the level of detail of the available data it was restricted to building elements: windows, doors, cornices and chimney stacks as well as street furniture, trees etc.

Architects and planners have a concept of Levels of Detail (LOD) based on the paper scaled representation of real space (1:5000, 1:1250, 1:500 etc). Projects very often are seen in scales up to 1:100 or 1:50 for a building, which means a building is isolated and examined at a higher level of detail. However, there is no such concept as spatial structure within different levels of detail. The whole area is sequentially “worked” at different levels but it is never visualised with varying levels of detail at the same time (maybe VR’s way of “seeing” the environment is going to be accepted and approved by engineers - it is simply the way the paper based representations are structured that causes this behaviour). The closest concept to organising information in building practice is to use BLOCKS/ INSTANCES/GROUPS (naming conventions used on different modelling software) where a set of objects are joined together, defined as one, and used in various other places without the need to redefine their geometry.

Implementing LODs on VR urban models needs a completely different approach. A highly detailed urban block may be over 20,000 triangles. One cannot expect that more than a few such blocks will be easily navigable considering current graphics hardware capabilities. A low polygon count representation (30-50 triangles) of each urban block should be used instead, when the camera is a few hundred metres away. However care must be taken as there is a threshold on how many LOD calculations are acceptable, versus geometry / texture use. For example, deciding to add textures on building facades, and switching them on and off per building using LOD nodes will bring the application to a halt, not because of the burden of loading all these textures, but due to the need to do all the LOD checks for each building on each camera movement! It is better for the browser to do tests for 4 LODs per urban block than 200. This leads to a sub-structuring of the model into streets within each main urban block. Long streets may be further subdivided in length.

The following structure has been developed by the author and successfully tested at the Bath city model (Bourdakis & Day, 1997). The four levels of detail are:

- **Level 1** a simple volumetric description of each terrace with a flat roof at the average height for that terrace (typically under 200 triangles per urban block). Roads, pavements, and landscape areas are also added in.
- **Level 2** each building is modelled with accurate wall and roof geometry and tagged as a separate object in the model. This means that each property in the city can be identified and used for data linking. Trees that are within the urban block are also visible. Visible at 150 metres.
- **Level 3** windows, doors, parapets, party walls and free-standing garden walls are added. It should be noted that not all windows, doors etc. of an urban block are under one LOD node. LOD nodes are created on the basis of keeping concise, more or less square (in plan) areas together. This usually means organising them per street facade. Visible at 90 metres.
- **Level 4** architectural detail such as chimney pots, string courses and pilasters are added. At this level, some photographic texture maps are also included on windows and shop fronts. The Level 3 structure is kept and Level 4 is visible at approximately 60 metres.

Landscape modelling is an issue addressed differently in 2D modelling and VR applications. The main problem is the continuity of the landscape and the inability to use LODs as described previously–having different resolution tessellated models of the landscape to exchange at set distances is a very resource consuming exercise. GIS companies have researched this issue and there are terrain visualisation solutions available (Terravision by SRI International www.ai.sri.com/TerraVision/:May 2001) that will have to be integrated with the urban model.

Having converted and optimised the dataset to VR the final issue that has to be considered is the process of updating the city database. Typically, there will be alterations to the city model (either because of new developments or via the use of the VR model in planning evaluation stages etc). Since most VR platforms available are not suitable for real-time editing of the underlying geometry, the CAAD database must be updated and the relevant alterations re-exported to VR–effectively establishing the CAAD database as the basis of all development work.

Utilizing digital city models

Implementational scope for city models

Urban VR models can be broadly classified under three main categories (Bourdakis, 1998a): *design and planning, education and general research* and finally *commercial and entertainment*. It should be noted that implementational directions vary greatly according to the application scope with certain tasks being clearly more suited to other media.

Design and planning oriented city models demonstrate (Shiffer, 1995) how and to what extend computers will be used in the near future by engineers as part of their everyday practice, creating, modifying and improving our cities online using centrally stored sharable databases (Day et al, 1996). Due to the nature of the proposed use of such models, the low polygon count fully texture mapped model approach adopted by more commercially oriented projects (Virtual Soma www.planet9.com/vrsoma.htm:May 2001) is not feasible lacking severely in accuracy and detail.

Over the last decade, the potential of VR as a teaching aid has been under investigation. Research however has focused on primary and secondary education and as such, urban environments have not been employed. The closest to urban scale projects are investigation studies on spatial ability via "you are here" type of maps for pre-adolescents (Phillips, 1997). Research work, investigating abstract data representations based on architectural notions of space such as *Vector Zero* and CASA's own *"Map of the Future"* where the digital city becomes the front end facilitating navigation, should be noted.

Implementing urban VR applications in commercially viable fields is quite different to research and development. The implications and return of investment is one issue that is extremely difficult to assess and thus persuade the client. Consequently, the "wow" factor and the hi-tech issue is the main selling point of the technology at it currently stands. This is clearly demonstrated by the various urban VRs (in the loose sense of the term) created to enhance, improve virtual shopping mall applications which grow is a fashion similar to that of shopping TV channels last decade. Typical examples are North American city centres, focusing on the prominent city landmarks (mainly skyscrapers, large office blocks and distinctive routes), which are pasted on a 2D map of the area. Detail is scarce, accuracy is questionable, conveying of information is not an issue, quality of the image is fairly poor and not appealing or even attracting attention, questioning their financial and commercial viability.

Concluding with the potential uses of urban VR systems, it should be stressed that in many of the examples discussed above, the notion of a city space is used loosely, denoting the various ways people perceive cities. It may vary greatly from one building complex, to a High Street, a neighbourhood or indeed rarely a whole city.

Limitations of VR

An analysis on creating standards for VR urban models would be incomplete without some warnings and a future work section criticising design or implementation limitations of VR applications as they stand today (Bourdakis, 1997b).

VR applications' ability to handle the sheer size of the models involved. Even with careful planning and use of LODs rendering frame rate is suffering. Large triangle based models are not supported very efficiently since software engineers focus on primitive based models. Furthermore, accuracy is not highly valued amongst VR developers and the need for three decimal points is often seen as excessive and wasting resources.

The lack of copyright protection or digital signature stamping in the geometry together with the ease of transferring files across the Internet is hindering the development and availability of urban models.

VR applications are largely customised for repetitive geometry, tasks, behaviours etc. Once that fails to be the case, VR apps tend to be inefficient and slow. Furthermore, hardware seems to be badly tuned for VR related tasks—typically available hardware provide either good CPU performance and low graphics (PCs), or the opposite (graphics workstations)

Navigation is another issue that needs serious consideration. In paper based environments, everything is right in front the engineer's eyes—the only tool needed is a large drawing board. On the computer screen, in non-VR approaches, the screen is viewed as a “window” to a much larger drawing, plan view is the one used most of the time. In a VE, the screen size or HMD limitations force us to an approach closer to the CAAD one. However, a plan only view is unacceptable, walking on ground level confusing and generally disorienting (Bourdakis, 1998b).

Results – Proposals for VR city models standards’ development

Summarising the issues presented in this paper, the author proposes a set of rules for future urban scale VR models: Plan compatibility by modelling based on existing 2D plans, Standardization on units, Origin–relative coordinates, five LOD construction (the four described plus textured landscape form), VRML 97 format for delivering the 3D geometry, library of reusable complimentary elements (street furniture, trees, etc) work on metadata–ways of mapping information on the model. This is by no means an exhaustive set of rules but a starting point for further discussion and development.

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