

# Introduction to HDRi and the LightLab Project

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## INTRODUCTION

High Dynamic Range (HDR) imaging [18] is a digital photographic technique that composites together a number of differently exposed conventional digital images of a scene to produce an image with a higher and more accurate brightness range, which is numerically coded into the image format. Common HDR image formats are Radiance RGBe (.pic/.hdr extension) and OpenEXR (.exr extension). The digital workflow for this photographic technique was first revealed in 1998 [4] and was intended for the generation of realistic lighting sources for virtual environments. Subsequently, it forms a direct relationship between physical site and digital design, and as such provides a viable tool for the teaching of the technical aspects of light within an architectural context.

## EDUCATIONAL CONTEXT

The use of HDR imaging in this architectural education context has sprung from the desire to more closely match core technological teaching with studio design work.

The optimal approach to the teaching of design and technology in an architectural education context has been often debated [20], and perceived to be problematic [1, 7], but the need has never been greater for architects and other built environment professionals to understand the relationships between the environment and the buildings they construct [10]. If environment and design are taught in isolation then reliance is placed upon students to find their own discourse between the two in order to satisfy both these elements of their curriculum. If the two are integrated then a more 'complete' design education can be delivered [20], but the issue then becomes how to make environment and design relevant to the eachother throughout the learning process.

A number of approaches have been used for the teaching of lighting in architectural environments, and its importance is clear from the number of lighting specific analysis aids that have been designed for architectural use. These include: basic rules of thumb, the LT method, Daylighting nomographs [15], BRS protractor [15], GDDM [14], Leso-Dial [16], Radiance [11] and agi32 (<http://www.agi32.com>).

One approach used staged physical and computational exercises [7] which have been successful in terms of 'hands-on' experimentation, but less successful in the latter stages at the application of lighting to architectural form. Another [13] used model making as a vehicle for, firstly, precedent study, followed by a student's own design, with a final calculation assignment based on studio work. Another [6] also used scale physical models to allow students to successfully test and develop daylighting design systems. An extensive program of lighting education at the University of Washington based upon physical experimentation [13] is another. Yet another moved from a theoretical to a progressively complex analytical approach [5]. It is clear from these studies that enabling students to undertake 'hands-on' experimentation and iteration is one successful approach to the teaching of lighting.

The use of HDR imaging presented here attempts to maintain this success by enabling easy experimentation and play whilst teaching light in a manner directly related to the actual site in which an architectural intervention is proposed. This directly addresses both technology and design by introducing a technological process (light) that directly improves final digital visual output. The importance of the role light can play in this context has long been recognised [13], and its influence on the entire design process, incorporating both the aesthetic and the technical, has been noted. These technical and aesthetic qualities make it an ideal vehicle to increase understanding between, and integration of, design and technology in architectural education.

Although the physical approaches mentioned have an invaluable tactility there are some advantages that modern computational techniques can bring to bear on the subject. Faster design iterations, full scale models, almost limitless material and form flexibility and, with HDR images generated at the proposed site, a direct connection to the environment of the students' buildings, are all more easily achieved in the computational realm.

Students can, for example, follow the lighting data they themselves have generated from acquisition at their physical site, through analysis and design iteration, to final presentation. This has a number of advantages in this context:

- The lighting data they gather is specific to their site, weather and the time of day that the original photos were taken. This strengthens the connection between real context and subsequent design work.
- Initial acquisition of the bracketed shots is easily integrated into existing physical work (e.g. site survey).
- This physically generated data can easily be integrated into existing digital workflows.
- Once embedded within the digital workflow, optimisation of design in terms of materiality and form can be achieved from the perspective of real lighting conditions. Lighting analysis in architectural education is too often a form of evaluation rather than as a *constituent element of the design process*. This feature of the use of HDR imaging serves to facilitate this *critically important iterative integration within design*.
- The integration of this quite technical data improves the visual quality of the final work, which helps maintain student engagement in an arts orientated discipline.

It has been argued [17] that computing has merged so integrally with design studio that its co-existence with design has become seamless. Its use, however, has predominantly been only to compose, manipulate and present form, and this research argues that the ability to assess function and site-specific performance is required if computational capability is to be optimised in design and design critique.

## GENERATING HDR IMAGES

### Introduction

The two most common techniques for the generation of HDR panoramic images, mirror ball and panoramic [2], were assessed for ease of use and quality of final image. Although the mirror ball technique has some advantages in terms of ease of use, as fewer shots are required, the relative complexity of software post-processing and difficulty in achieving good quality images makes the panoramic technique more suitable for this context. To reduce the relatively high number of shots required to create a 360° panorama this way a fish-eye lens has been used. This limits the number of distinct sets of bracketed shots required to four. The immediate ground in the scene is missing (Figure 1), but for most lighting scenarios where the majority of lighting comes from the sky or more distant ground this has been considered an acceptable trade-off for simplicity.

An additional consideration for the completion of the HDR generation workflow is the software required to composite the images taken into one HDR panorama. Fortunately the free, open-source and multiplatform photo stitcher Hugin can natively composite and stitch bracketed shots into complete 360° HDR panoramas.

### Final Set-up and Workflow

After investigation into different hardware and software options the following set-up was chosen:

- Camera – Samsung gx-20 (up to 5 bracketed shots in 2EV steps)
- Lens - Samyang 8mm, aspherical, fish-eye lens
- Software - Hugin, open source, free and multiplatform panorama stitcher.

The camera delivers an 8EV range in the bracketed shots, which although still not high enough to capture full brightness range between direct sunlight and darkness [19], visually comes quite close when rendering virtual scenes.

The lens is an aspherical, or full-frame, fish-eye lens with a 180° corner to corner, 154° horizontal and 102° vertical (in landscape mode) field of view. To capture a full scene (excepting the floor beneath the camera which is not generally so important for lighting, and contains the camera tripod) the camera is tilted into portrait mode, tilted up 20° to capture the zenith and then 4 sets of bracketed shots are taken at 90° to each other. As the camera (in portrait mode) has a horizontal 102° field of view, these 4 sets of shots can just capture the whole 360° of horizontal view.

The Hugin software is one of the few software programs that can generate HDR images (EXR format) and stitch them together into a panoramic, or light probe, format. Hugin can export equirectangular projected images which equates to the polar, or lat-long, light probe format (Figure 1). Most image stitching packages



Figure 1: Final tonemapped HDR panorama of an interior scene.

work on the principle of finding common points in the overlapping portions of the images and using them to orientate the images with respect to each other, and this is also the case with Hugin. Another advantage of Hugin is that once the lens and camera combination has been calibrated, every subsequent stitching only requires a few control points. In an educational context where a student might only be producing a one-off HDR light probe, this simplification of the process is very advantageous. Calibration of the lens requires 20 to 30 overlapping shots to be taken within a large interior space (Figure 1). The space should be as large as possible and only control points at the scene periphery used, to minimise parallax errors from the slight movement of the lens as the camera is rotated. The scene should be interior to ensure the environment is static (e.g. no moving clouds), and that there are scene features to calibrate image overlap over the whole 360° panorama (unlike a clear blue sky). The free and multi-platform nature of the software also obviously has key benefits in a student user context, and in this regard is superior to the OS X only PhotoSphere (<http://www.anywhere.com/>), which has similar capabilities, or the multi-platform but commercial PTGui (which acts as a front end to the same tools as Hugin) and PhotoMatix.

The overall cost of the system was approximately €900, which although significant, should not be prohibitive for most educational institutions.

## USING HDR IMAGES

An HDR light probe image represents brightness and directional lighting environment for the position and time the original bracketed shots were taken. When then applied as an environmental lighting source around a virtual 3D environment, any object within that environment is illuminated as if it was situated in the same time and place as the camera. Details of the lighting environment are captured, so the subtleties resulting from overshadowing, reflection from surrounding objects etc. is also maintained within the image. The application to architectural site surveying is clear.

Once an HDR image is in a common light probe format, like angular map or lat-long, their integration into digital design workflow is easily accomplished. Most renderers, either stand-alone or integrated into 3D modelling packages, can accept the light probe as an automatic scene light source. Usually it is no more involved than picking the requisite file from a dialogue and possibly orientating it to match the orientation of the 3D model. At the University of Brighton's School of Architecture & Design Cinema4D and Blender are extensively used, and both accept HDR panoramas as an environmental light source. This is a key advantage of HDR imaging in a design education environment, especially architecture, as students will be familiar with these packages from 3D design elements of their course, and the integration of this accurate lighting data with their design work is thus streamlined. As long as the renderer used is of reasonable accuracy, rendered objects will look as they would at the physical scene. This is especially the case if using modern 'un-biased' rendering systems like Maxwell (<http://www.maxwellrender.com>) or LuxRender (<http://www.luxrender.net>) (Figure 2).

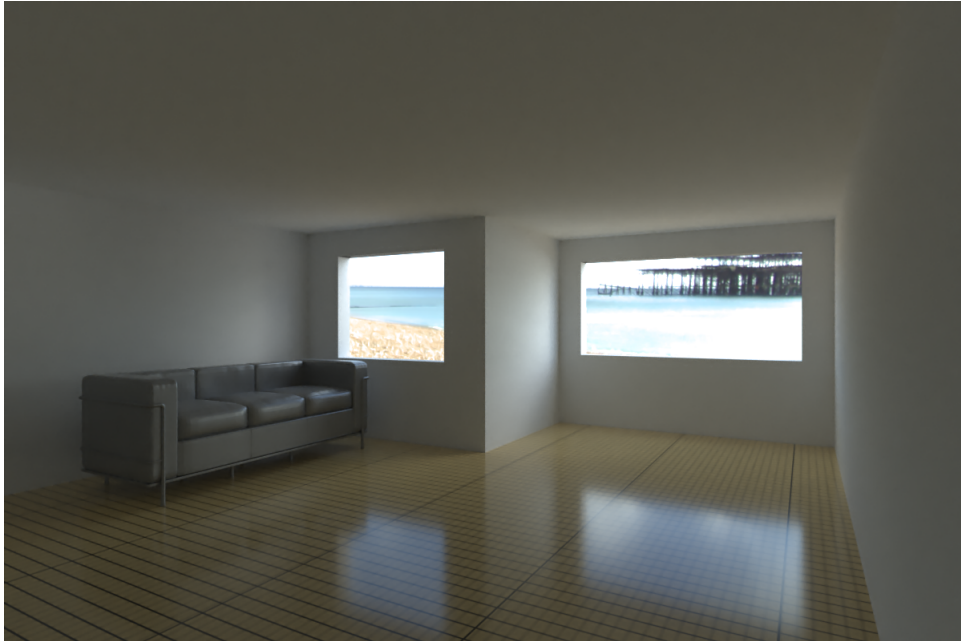


Figure 2: LuxRender rendering with HDR sky background.

One of the advantages of the panorama technique of HDR generation is the high quality of the final image. This allows the generated light probe to be not only the light source for a virtual scene but also the background, placing the student's virtual design very much in its correct geographical context.

## Quantitative Analysis

This initial work has centred on the qualitative analysis of site specific HDR lighting conditions, but quantitative analysis is also possible and the resultant site specificity can result in greater numerical accuracy than conventional quantitative analysis [8]. Achieving quantitative analysis with HDR lighting sources not only requires numerically validated HDR [9] source files, but a numerical analysis method that can take full advantage of the subtleties resident in the lighting source.

A central ethos of this project is the use of low-cost hardware that requires no great institutional investment, and enables student's experimentation and play. This presents some challenges in terms of achieving numerical accuracy. The camera used in this project has the largest EV range in the price bracket desired that could be found, but a range of 8 EV is still not enough to capture the whole dynamic range of a sunlight scene, which would require 17EV [19]. Calibration of the camera within the capable dynamic range would however generate accurate lighting sources for non clear sky scenarios. One method of achieving a greater range with the same hardware is to use neutral density (ND) filters [19] that consistently, across all wavelengths, reduce the amount of light the camera sensor is exposed to. Post-processing can later factor in the filter reduction to achieve accurate top-end brightness values. Although some resolution can be lost at the low end of the brightness scale this would usually not impact on absolute numerical brightness levels, which are dominated by the higher values. The use of a fish-eye lens for the easier generation of HDR panoramas makes their use problematic however as complete fisheye lenses are not built to take additional filters. This would then require extra equipment to hold a large ND filter in front of the fisheye lens that moves away from the desired workflow simplicity.

Another method would be to use the pvalue programme available as part of the Radiance package to alter brightness values within the image. Once the available camera equipment has been optimized to maximise the brightness values that can be sensed before sensor saturation then any above horizon light source that does saturate is likely to be the sun itself. One methodology under development is to use pvalue to calculate the altitude position of the saturated pixels within an HDR image, and use a python language script to assign a new brightness value to these pixels based on clear sky, and altitude angle, assumptions. This method does not currently take into account sky turbidity (pollution) or strong, saturating, above horizon, reflections in the scene and does, to a small extent, deviate from the genuine lighting characteristics of the scene.

Assuming an acceptable level of physical accuracy can be achieved, HDR images can also be used as input to numerical lighting simulation packages, such as Radiance [11] for the prediction of location specific lighting metrics. An issue with Radiance is its relative complexity of use, especially within the context of a design orient-

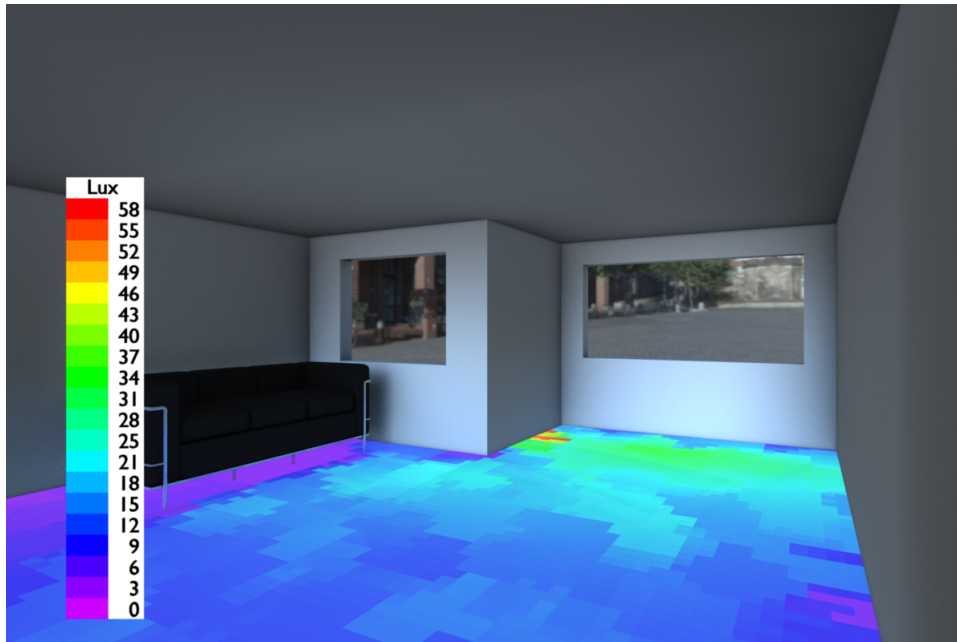


Figure 3: Blender rendering of Radiance results with an HDR sky background

ated learning environment [12, 3]. To maintain simplicity throughout the workflow a set of scripts have been written to interface the open-source modelling tool Blender with the lighting simulation programme Radiance. The student generated HDR panoramic skies can be specified as a lighting source within Blender, the scene exported to Radiance for simulation and the results brought back into Blender for visualisation. Any geometry within the 3D model, like a floor can be specified as calculation points for Radiance, which will then return values for the chosen lighting metric that can colour the specified Blender geometry. As the scripts hide a lot of the complexity of using Radiance, students would have access to a complete simplified workflow from lighting data acquisition, through analysis, simulation and design iteration to final visual presentation, both photo-real and numerical.

Blender offers a number of advantages for the visualisation of numerical Radiance data. Like Radiance it is free, open-source and cross-platform allowing students to install and use the software without licensing or compatibility issues.

Additionally, it is a polygon, as opposed to a solid, modeller meaning Blender geometry is composed of vertices, edges and faces as opposed to mathematical descriptions of form. This is advantageous here as Radiance, via its rtrace component, can calculate lighting metrics at particular Cartesian points within the 3D virtual scene, and these points can be corresponding vertex or face co-ordinates of the Blender geometry. Generating sensor points within the model is therefore as simple as designating existing geometry with the requisite grid resolution. Another advantage is the ability to colour geometry at the vertex or face scale. This is an unusual ability in 3D modellers and results from the use of Blender to create game environments, with baked-in textures, using the inbuilt game engine.

Blender's use of the Python scripting language to control the Blender user-interface, model geometry and materiality, coupled with Python's excellent text processing and programme control capabilities, allows for the automatic control of Radiance and the creation of user interface elements that customises a sub-set of Radiance parameters presented to the user.

Finally, and perhaps most importantly, Blender is a complete visualisation and rendering suite (although not a CAD environment). Traditional visualisation work can therefore be achieved within Blender and numerical lighting analysis can be quickly accomplished without having to learn a new software package. This encourages quick and iterative play, which has proven to be the most effective element of the physical teaching methods previously discussed.

## TEACHING PROGRAMME

The qualitative and quantitative methods laid out above were presented to the student body at the School of Architecture & Design in three different ways:

- Initial presentation of the above techniques and learning resources with studio staff at the start of the academic year/specific technology programme to the whole student body, to encourage self-directed student learning.
- An 8-week course, broadened to include students from graphic design, working through the process of HDR panorama creation and its application to the illumination of virtual space.
- More intense, unit related, sessions to a sub-set of students on HDR acquisition and quantitative lighting analysis with *LiVi*.

## Self-directed learning

The learning resources created for the project were placed on the University's intranet system, *StudentCentral*, at the beginning of the academic year. Camera hardware was left with technicians and a system for loaning out the hardware, similar to existing photographic equipment, was formulated. Undergraduate students on both the Architecture (2<sup>nd</sup> & 3<sup>rd</sup> year) and Interior Architecture (3<sup>rd</sup> year) courses, as well as the both years of the Architecture MArch, were given an introductory lecture with studio staff detailing the process of borrowing the camera, location of learning materials, further assistance they could expect, detailed description of the process itself and example work resulting from it. In the case of Interior Architecture this was timed to coincide with a site visit, and for the other two courses the beginning of specific technology programmes.

Students were then extolled to apply these techniques to their studio programmes, working initially with their building sites to capture lighting details, then to test and refine initial design ideas and finally visualisations for their final portfolio.

This approach raised a number of issues however.

### Site access

On the MArch course a busy location outside of Brighton was given as a site location. Through tutorial and student feedback it was clear that many students were reticent to carry what they considered to be expensive photographic equipment to site with them. Of those that did getting good clear panoramas of the area was difficult due to the high number of members of the public at the site. This is a key point when asking a student to use a specialist piece of equipment. As University insurance policy did not cover the cost of the camera students were made aware upon loaning the equipment that they would be liable for its cost should anything happen to it.

On the architecture programme various existing private housing sites were chosen for intervention, again making site access in some cases problematic.

Also in relation to site access the Interior Architecture programme had a private site with limited access, meaning many students only visited the site once for survey.

The site chosen for the 2<sup>nd</sup> year technology programme was much more suitable as it was the School itself, and presented no barriers to student uptake.

It appears to be key therefore that relatively unrestricted access to a site, that represents a controlled environment, is necessary for the maximum engagement with specialist equipment.

### Credits

With this self-directed learning approach no credits or marks are attached to the successful use of HDR imaging. It is more a resource that students, although encouraged, utilise depending on their studio work, inclination and associated skills. That can present a challenge to successful uptake however, as work that carries credits will be focused on and unless uncredited work is seen by the student as achieving the goals laid down by a credited part of the course, they will not on the whole greatly engage with it. Although too specialist maybe too warrant credits itself, the methodologies laid down here could be officially identified as one way for a student to make progress towards a credited goal. This does however require an even greater level of integration with existing units.

### Studio work

An issue related to credits issue above is the relationship between the techniques taught and design studio work. Although every attempt in terms of timing was made to make the techniques relevant to the activities in design studio, it appears that a specific request for the techniques to be employed from design studio staff is required for mass uptake.



## Taught course

The generation and use of HDR panoramas as a source of virtual illumination was taught on an eight week extension study course within the University of Brighton's Faculty of Arts. 13 students from the Architecture and Graphic Design schools took part. The course was broken down into the following sections:

- Introduction to HDR imaging and its uses covering illumination of virtual space and tone-mapping for artistic purposes.
- Hardware and software techniques for their generation, specifically:
  - Using the panorama technique, with auto exposure bracketing, to take the foundation images.
  - Stitching of the images within Hugin to create a seamless panoramas
- Students identified and justified an interesting site within and around Brighton, visited it with the camera equipment, and shot the foundation images.
- Stitched the images together to form site panoramas.
- Introduction to Blender and 3D modelling.
- Using HDR panoramas in Blender.
- Animation in Blender.
- Physics in Blender.
- Final composition and rendering of images and videos.

The final hand-in for the unit was a set of images and videos based on their final renders along with a discussion of the relevance of HDR imaging to their discipline.

A focus group meeting was held at the end of the course to gauge opinions on the course content and structure and identify areas of improvement.

11 students completed the course and engaged fully with the all aspects of it. Allowing a student to choose a site meant that they could choose a site they liked, or could easily gain access to, reducing the barrier to the use of the specialist camera equipment.

Using free and multi-platform software tools throughout meant that students could work with their own machines, away from the weekly sessions. This was key as many of the concepts raised during the course was new to the students and the ability to play and familiarise themselves with these techniques out side of the sessions was invaluable. The course also had 10 credits associated with it, which although modest in itself, maintained good student motivation.

## Student Feedback

Below are the student responses to a set of questions from a focus group meeting held at the end of the course.

### **How could the teaching of HDR Imaging for the illumination of virtual space be improved?**

- Using the HDR techniques learnt in the course for the creation of 2D artistic tone-mapped images rather than 3D illumination would have been preferred by some students, especially those that did not concentrate on the 3D aspects of their design work. For these students it was the first time they had really engaged with 3D digital content creation, and the course was therefore quite challenging.
- Within this 3D the process of animating 3D space was seen as being useful for its potential to make the presentation of their work more dynamic.
- For those students that were already familiar with Cinema 4D it would have been better if Cinema 4D had been used for the 3D work. Blender, however, was for these students easier to learn than Cinema 4D.
- The fact that architectural 3D digital models were not specified was not an issue as any model teaches the basics of digital 3D.
- It would have been better to follow one complete workflow example from beginning to end, by watching the tutor do it step by step, rather than learn each stage separately.

- The course covered many aspects of digital content creation and focusing on fewer aspects might have been better. There was however multiple opinions regarding where the focus should lie: some felt that removing the 3D geometry creation part by providing a 3D model would have been better, while others felt that focusing on the panorama creation and tone-mapping could have been focused on.
- There was a general feeling that the course was too technical, and not artistic enough, although one student found the technical elements the most useful.

#### **How could HDR imaging be useful in terms of your respective courses?**

- HDR imaging can be useful as an architectural site survey technique, but there was an appreciation that the HDR panorama only captures the lighting conditions for a moment in time.
- HDR based lighting offers better realism, and using generated panoramas for the production of visualisations is valuable. There is often a requirement or desire to produce 3D work and this can be one way to improve the presentation of that work.
- It was also appreciated that using HDR based lighting meant that no positioning or creation of artificial lighting sources within the 3D program was required. This can save time as the art of using conventional lighting in 3D virtual scenes to produce good results takes time to learn.
- HDR lighting in the context presented here is better for visualisation rather than analysis.
- Visual lighting analysis is currently done with physical models. The physical method is more time consuming but there is more flexibility in the solar positions being studied. The digital method can give greater scope for material experimentation with digital material characteristics matched to physical ones.
- Animation could be good for walkthroughs. Showing the dynamics of the building doors opening etc. Would be useful to animate over a day with different images, but would still be to some extent limited to the times of day studied.

#### **Unit Based Analysis**

A version of the *LiVi* scripts for the previous 2.49 version of *Blender* was released to a sub-set of 3<sup>rd</sup> year architecture students who had previously shown an interest in digital/environmental design. An initial session demonstrated the use and installation of the *LiVi* scripts, which were available for download to students with Mac computers, and pre-installed on a set of Mac computers within in the school.

Students were encouraged to use the scripts and the results generated to refine their existing building designs, from a lighting point of view, and present these refinements as part of their technology unit of study. Good use of the scripts and the conclusions formed from the results did therefore contribute to a unit mark, and again maintained good student motivation.

Although the students were new to *Blender* and lighting simulation in general, the intentional ease of use of the scripts meant that meaningful work was accomplished and intelligent design decisions made. More could have been accomplished, however, if students had previous knowledge of *Blender* and its modelling/rendering workflow, as much time was spent getting geometry into *Blender* and the results back out for final rendering in Cinema 4D, the use of which most had been taught before.

This raises interesting questions of which, how many, and for what digital tools are taught to architecture students. Currently they are primarily used as a display mechanism, or visualiser, for 3D form that may in turn have been imported from a CAD package. In this regard Cinema 4D is a valuable tool, but digital activities cover a wide spectrum of topics including rendering, automated or parametric form generation, numerical analysis, physical simulations etc. A tool more broad or extendable in its capabilities has a lot of value in this context, as it simplifies learning by requiring navigation around fewer user interfaces. *Blender* is a good candidate in this regard as it is fully scriptable, flexible and already has a multitude of extra capabilities added from a thriving on-line community. It is the intention to write a new set of scripts to interface *Blender* to the Energy+ suite of thermal simulation tools for whole building energy analysis.

#### **Student Feedback**

##### **What were the main usability factors in using the *LiVi* scripts?**

The interface itself, specifically the lack of feedback regarding errors/crashes in workflow. The inability of the *LiVi* scripts to deal with file names or directory names with spaces in.



Confusing how *LiVi* rendered and saved the rendered files. Most students rendered from Blender in the end.

*[The new set of LiVi scripts now has better error reporting and ability to deal with spaces in material and object names. Rendering from Blender is now the default option to avoid rendering workflow confusion.]*

**What was the main benefit of the *LiVi* scripts?**

It was handy to be able to visualise lighting in a virtual space. Allowed the student to stop guessing at design decisions and make them instead.

Very good to get numerical results, students did not think they would have the opportunity to do that.

**What was the main limitation?**

Could not produce a vector file of the sensor geometry and colouration would could be imported into illustrator or C4D. Could not take models in with material definitions, could not render results with final material definitions. Would be nice to just use one piece of software for the whole process.

*[To some degree this requires better knowledge of Blender as it has similar geometry building, material creation and rendering capabilities as Cinema 4D. Blender has experimental support for the Collada 3D file format and this will be investigated as a file transfer mechanism as it promises better material data transfer. The possibility of exporting an SVG file of the results plane for import to Illustrator or other vector editing suite is to be investigated.]*

**How can you imagine this software being most useful educationally/professionally? For example at the beginning or the end of the design process?**

In a professional design process it is something to refer to all the way through, but this requires good model transfer.

Educationally it should also be referred to all the way though, and the student gains more ownership of design. Intensive workshop at the beginning would allow the student to use as they see fit. Another tool to make informed design decisions. Internationalisation i.e. the ability to set latitude and longitude is a positive factor.

**In what element of Architectural design does *LiVi* encourage the most experimentation?**

Form, and the geometric methods of getting light into a space. Lighting related technological interventions.

**What extra capabilities would be useful?**

Not used to it's fullest, better description of it's features would make them more likely to be used. Legend display that describes the activities that can be done with that lighting level, and how good the Daylight Factor is.

Realistic renders with the results included. Visual and technical together.

More description of Daylight Factor would have been good.

*[More options for legend display are planned to be included in the LiVi scripts including activity type, and qualitative description of lighting levels. Inclusion of documentation within the LiVi scripts that can be viewed by the user. The LiVi scripts now create an HDR sky for illumination if a standard sky description is chosen.]*

## CONCLUSION

The LightLab project has investigated the use of physically and digitally generated HDR panoramic images to produce visual and numerical analysis of virtual design space.

The physical generation of HDR panoramas centres around an optimised open-source software, and low-cost hardware, platform which allows easy generation of high quality HDR images.

These HDR images can then be used for visual analysis of virtual space with the use of renderers, or used as a source of illumination for numerical analysis using the *LiVi* set of scripts that allows creation and visualisation of *Radiance* results. The *LiVi* also allows the creation of custom HDR panoramas delivering more flexibility in terms of times of day studied.

The resources created for the LightLab project have been taught to the student body in three ways: tuition followed by self-guided learning, within a specific HDR course structure and as facilitating technique to a technical unit of study.

The first of the three was the least successful for the issues highlighted above, the main one being the divorce of the use of HDR imagery with course marks. This will preclude its use by many students who often have to prioritise many activities as part of a holistic design course like architecture. In this context it is vital that studio staff specify its use as one way of achieving a particular aim of relevance to a marked unit.

The second teaching method was much more successful in part as it avoided the issue above by having course marks associated with the final outcome. The marks associated with the course were not very large and constituted 100 student learning hours in all. Another advantage with this format was that students could pick their own site for investigation, to which in general they had free access. The structure of the course, although

very specifically about the inclusion of student generated HDR lighting sources into digital design workflows, covered aspects of lighting, 3D modelling, animation, physics simulations and rendering. Students picked a variety of different locations for a number of different and interesting reasons. Some concentrated on the quality of light at certain times of the day, others on the human activity at the site and the interplay between human time scales of movement and the staggered photographic process. There was also an interesting split between urban and rural contexts.

After building up their HDR panoramas of their scenes they were applied to a variety of digital models, static and animated, of their own construction. Again a large breadth in the type, form and materiality of object and style of animation was present. Within a visual HDR rendering context, highly reflective surfaces are popular as they reflect the background and create an additional realism to the scene. This was the case here with many students liking the reflection of the scene on their object, and the interreflection of objects between themselves.

Feedback was also generally positive with most students of the opinion that the course was useful and interesting. Some felt the course was too difficult but these students also produced good work.

The third teaching method concentrated on numerical lighting analysis and although not in a specific course structure, ran parallel to a technical unit of study, and made clear to the students that lighting simulation could be one way of achieving some of the aims of the unit. The students using the technique therefore chose it as a way to achieve unit based goals. This method seemed to bridge the gap quite well between a specific course based structure and free, self-guided learning, as students remained motivated but were free to apply the techniques to their technical unit of study as they saw fit.

Once having learnt the process of achieving numerical lighting results students engaged with it in a way relevant to their technical design work. One student was concerned that a lightwell they had designed would not provide enough light at the right time of day. Numerical simulation allowed then to quantify this problem and design and test roof structures to improve it. Others were concerned about overheating and developed shading systems to mitigate the issue. Others tested different types of materiality both in terms of surface finish and constructional elements to improve lighting levels at certain key points within their design.

A key feature of this third method is the ability it gives a student to play with design, quickly and iteratively, from a technical perspective and does go some way to achieving the original aims of the project i.e. to seamlessly bring together technical and aesthetic elements into a design process. It is also this 'hands-on', playful, element to lighting analysis and design that has proved to be the most successful component of the previous, more physical methodologies, that have been tried elsewhere.

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