Photogrammetry as an aid to lighting design for industrial interiors

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Photogrammetry methods have been shown to be useful as a tool for investigation of illuminance distribution and light losses in interiors containing obstruction configurations that approximate to simple rectilinear objects. This work examines the use of photogrammetry to model obstructions having a greater degree of complexity and a case study demonstrates the applicability of the technique to lighting design for a factory. The results confirm that this technology would accelerate the process of incorporating the effect of obstructions in routine lighting analysis and design.

Keywords: Photogrammetry, lighting design

Introduction

The subject of design and analysis methods for lighting in obstructed interiors has received attention in recent years. Traditional lighting calculation methods assume a clear room volume and make no allowance for the influence of obstructions – objects located between light source and task which act to block, absorb or reflect light. Obstruction may cause local variations in illuminance (for example over a task area) and an overall reduction in planar illuminance over a whole installation. Many software packages for analysis of illuminance from electric lighting installations are available. Most are based on the ‘empty room’ approximation – the absence of obstructions. The majority of packages that are capable of quantifying the effects of obstruction can only be used when complete details of the room, contents and lighting system are known. Where this is not the case (e.g. speculative office or factory buildings) the nature and layout of furniture or machinery will influence both overall light losses and the distribution of light in the installation in its working state. Methods now exist to quantify light loss in some types of speculative buildings (Carter 1997)

Photogrammetry is the science of making measurements from photographs. Previous work introduced the use of photogrammetry as a tool for investigation of illuminance distribution and light losses in obstructed interiors (Hadwan, Kaka, Knight and Carter, 2000). This work looked at two main uses of photogrammetry for lighting calculations in obstructed interiors, firstly, the description of obstructions so as to estimate light losses, and, secondly, as an aid to modelling obstructions for input to lighting analysis or CAD programs for subsequent calculation of light loss. The first technique is based on the relationship between Obstruction Loss (OL) (the percentage reduction in average working plane illuminance caused by uniformly distributed obstructions) and the obstruction density (the size and disposition of the room contents) for generic types of luminaire. Obstruction density is quantified by the ratio of obstruction vertical surface area to floor
area (VFR). Photogrammetry was applied to obstruction configurations made up of, or approximating to, simple rectilinear objects.

The work described in this paper examines the use of photogrammetry to model obstructions having a greater degree of complexity. A case study demonstrates the applicability of the technique to lighting design for a factory.

**Light loss in complex interiors**

The concept of Standard Obstruction (SO) has been put forward as the basis of estimating light losses likely in office buildings whose ultimate use is not known (Leung, Lupton and Carter, 1994). In a commercial building obstruction may include visual display terminals, filing and storage cabinets, panels and screens used for dividing offices into workstations, and also users of the office when seated at desks. Standard obstruction configurations were developed from analysis of data on office furniture and represent the range of obstruction density found in typical office interiors. To date the standard obstruction approach to prediction of light losses in speculative interiors has been limited to offices, which may conveniently be modelled for lighting simulation purposes using ‘rectilinear obstructions’. There is strong evidence that this approach can be used to predict light losses in working office interiors.

Unfortunately simple rectilinear objects cannot accurately represent the obstruction configurations in most non-office interiors. Industrial and storage buildings, for example, come in a multitude of shapes and sizes and are likely to contain objects of diverse shape, layout and distribution. These interiors may be considered to have ‘complex’ obstructions, and modelling of the light blocking surfaces within buildings of this type is difficult using any of the existing standard obstruction techniques. A substantial body of data for prediction of overall light loss based on the relationships of room geometry, contents and light source exists and could be extended to types of speculative buildings other than offices. The main barrier to this is that the contents of these types of interior are more difficult to model for purposes of estimating light loss than the ‘rectilinear obstructions’ found in offices. This work examines the use of photogrammetry to model obstructions having a greater degree of complexity than standard obstructions.

Photogrammetry software produces three-dimensional models based on images of the object made from known locations. The procedure entails importing an image either by scanning printed photographs or directly from a digital camera. ‘Object points’ (typically corners) are then marked on the images so as to enable the three dimensional model to be constructed. Marked object points on the different photographs are then identified and referenced. The software uses the camera positions and orientations to calculate co-ordinates of every marked and referenced object point and the result is the basic three-dimensional model with estimates of errors for every point. A model is scaled by entering into the program a distance between two object points. Once a model is scaled and augmented if necessary, it can be exported to other packages to act as the basis of lighting calcula-

*Figure 1. Experimental lighting installation*
Accuracy depends on several factors, notably the quality of the camera used, the viewing directions of the photographs, the number of photographs on which each point is marked and the capacity of the software to interpret the image (for example recognition of hidden or partially hidden surfaces). The experimental lighting installation, constructed in the School of Architecture (figure 1), was photographed using a calibrated digital camera.

A minimum of four photographs was taken of each installation so as to include detail of both the building fabric and contents. The images were processed using Photomodeler, a low-cost photogrammetry program. This commercial software, widely used in practice, was used because of its ease of use and low cost making it ideal for this study. An example of an image marked with object points is shown in Figure 2.

Once the images had been processed in Photomodeler the resultant three-dimensional model was exported in DXF format to AutoCAD and a three-dimensional model of the building interior constructed into which the digitised contents were placed (Figure 3). The three-dimensional model was initially used to check the VFR values calculated for the various obstruction using dimensions from the physical survey. An LISP routine within AutoCAD was used to query the database of the objects in the model to extract the vertical surface area of the obstructions above the working plane and hence calculate VFR. It should be noted that both of these processes were extremely time consuming.

Finally using the survey measurements a further series of three-dimensional AutoCAD models were constructed for each combination of obstruction configuration and luminaire. These were for comparison with those derived directly from Photomodeller. The three-dimensional models were then transferred to Lightscape to simulate working plane illuminance in the various models. The resulting values of OL acted as a cross check for the other calculation methods. The
resulting values showed a close correlation with the calculated values

**A case study of lighting design using photogrammetry**

The technique was used in a redesign of the lighting layout of a factory, situated in north Liverpool, which produces paper and cardboard packaging products. The replacement of the existing lighting was necessary because of major changes to the layout of the production area including new machinery and a desire for a better lit environment using more energy efficient equipment. The case study gave the opportunity to survey the factory in its original state, advise on the redesign of the lighting to achieve the above aims, and to make a subsequent survey on completion of the work.

The building was single storey (50m long and 18m wide) with a portal frame roof 4.5m high at eaves rising to 6.0m at ridge. The roof decking incorporated a number of roof lights (approximately 1% of total area). The electric lighting system consisted of a variety of obsolete equipment located mainly adjacent to machinery. At the time of the initial survey the factory contained a wide range of machinery of complex shape some of which was to be retained in the re-layout and an area containing high rack storage served by fork lift trucks. The major items of replacement machinery were on site but, due to the need to maintain production, were not in their final location. The floor area between the machines was used for temporary storage, checking of products and for transport by means of fork-lift truck or similar.

The initial survey consisted of physical measurement of the building, positions of major items of machinery and, for scaling purposes, the main dimensions of some items of equipment. Illuminance measurements were made at critical task locations and across the available unobstructed working plane. Room surface reflectance values were measured. Photographs of the interior were taken with a calibrated digital camera that
enabled each machine to be located within the building (Figure 4). In addition detail of each machine (including the ones not in their final locations) was captured, the number of photographs depending on the size, shape and location of the object. A number of factors limited the scope of the photography. The physical constraints of the building meant that some machinery was in close proximity to walls or other machinery and hence difficult to photograph. The need not to disrupt production restricted access to some locations. An obvious limitation in a single storey building was that no views from either high or low level were possible.

The initial illuminance measurements were made as spot readings in working areas late in the day when there was minimal contribution from daylight. The average illuminance over the whole working plane (including the task and circulation areas) was 120 lux. This value was some way below the CIBSE Code for Interior Lighting (1994) recommendation for this activity of 300 lux and close to the Health and safety Executive ‘Lighting at Work’ (1994) minimum of 100 lux.

A CAD model of the interior was constructed from physical measurements and the photogrammetry generated models of the existing machinery added. The revised layout of the factory machinery was dictated by production requirements. The model was adjusted to give the final machinery layout including the insertion of the additional machines. (Figure 5).

Two alternative lighting schemes were prepared for the factory and the CAD model was
used to evaluate these. After discussion with the factory management, a scheme was agreed that proposed 17 luminaires in three lines giving an average illuminance over the production area of 250 lux. Finally an analysis was performed for the interior using Lightscape for a photometric analysis for the final machinery layout and the alternative lighting proposals. A Lightscape rendering of the case study interior is shown in Figure 6. The analysis enabled task illuminance to be determined at each machine and distribution of illuminance over inspection, transport and storage areas.

**Discussion**

This work has investigated two uses of photogrammetry for lighting calculations in complex obstructed interiors, namely, the production of VFR for use with ‘predicted’ data to estimate light losses, and as an aid to modelling obstructions for subsequent input to lighting analysis or CAD programs. The technique was applied to two lighting installations – the experimental space containing a number of types of lighting equipment and obstructions, and a working industrial interior.

The experimental space contained both standard and complex obstructions. The method of extracting VFR from the CAD model of the interior was accurate when compared with values produced by physical measurement. It may be questioned whether the sophistication of the former was necessary for standard obstruction type objects since their VFR is, by definition, known. For interiors with more complex obstructions the use of the CAD model is slightly less time consuming than using manual survey and has the benefit of enhanced accuracy. However the amount of effort involved in both processes renders them uneconomic as practical design tools. The predictions of OL derived from the historic data of OL/VFR for generic luminaire types agree well with the other measured and simulated values for standard obstructions. For complex obstructions the results are acceptable but somewhat more variable, possibly because the historic data was derived from standard obstructions. This work confirms that predictions of this nature are useful for installations those contents can be represented by standard obstructions for which VFR is known. The time consuming nature of cal-
culation of VFR, either wholly manually or having enlisted the help of a CAD model, suggests that this process is unlikely to be used other than for research purposes.

The process of measurement of OL in a space filled with complex obstructions is a painstaking operation and one that is unlikely to be undertaken as routine. There is broad agreement between the OL values based on measured and simulated data for the experimental space. As with the predictions of OL derived from the historic data the agreement is better for standard obstructions than for complex obstructions, the results for the latter exhibiting a variable pattern. There is good agreement between the Photogrammetry simulated OL and the ‘benchmark’ AutoCAD simulated OL. This suggests that OL may be estimated using the former technique thus avoiding the time consuming physical measurement of the installation required to construct the AutoCAD simulated model.

The case study permitted a trial of photogrammetry methods on a live design problem. The technique was used to model a building interior and contents, including equipment on a remote site, to produce a machinery layout. The two proposed lighting schemes were analysed to give predictions of average illuminance throughout the installation and task area illuminance conditions. These enabled management to make an informed choice between alternatives. In fact the low bay 250w scheme was installed. In general the technique gives a designer the opportunity to do detailed investigation of the lighting implications of proposed changes to lighting or production equipment under circumstances where a three-dimensional model of the interior does not exist. Most retrofit schemes fall into this category. The capacity to produce a model from a series of photographs is a major advantage. In some interiors continuous production prevents the gathering of the extensive detailed measurement required to produce any other type of three-dimensional model. The method could also be used to insert objects into an existing CAD model.

Although the technique of photogrammetry has been shown to have potential as a lighting design tool, a number of problems and limitations were encountered. The main problem related to the capture of enough information to permit translation of the photographs of complex environments within Photomodeler. A major barrier to data capture was the limited range of camera positions available within a building interior where high level views were usually difficult to obtain and low level views impossible, coupled with the low light levels which exacerbated the limited capabilities of the digital camera used. Ideally each object should be wholly visible in four photographs, each separated by 90° but in practice at least double this number were necessary. Even with a simple arrangement of standard obstructions it proved difficult to capture the image of each obstruction element and this was a greater problem still with complex obstructions. Once in the Photomodeler environment, the accurate marking of the individual object points proved difficult particularly where the furniture had little colour or contrast difference. The low resolution of the digital photographs in the experimental space viewed from a low angle made it difficult to determine exact edges and vertices. This was less of a problem in the industrial interior which had greater photometric and colour contrasts.

In any method of modelling a complex interior it is likely that errors will occur. The production of a conventional CAD model requires physical measurements or transcription in the ‘conventional’ surveys as a preliminary. The use of photogrammetry reduces the amount of physical measurement to that required to scale the image. On the other hand, errors can be made in the marking of the photographs or images in the photogrammetry program. These can be minimised
by increasing the resolution of the photographs and/or increasing the number of photographs taken of the obstructions. Many of the problems of image identification would be overcome by use of the more sophisticated photogrammetry programs that are now on the market which have better interpretive capacity including automatic recognition and modelling of specific configurations and hidden, or partially hidden, surfaces.

Conclusion

This work has extended previous work on photogrammetry in lighting design to interiors containing objects that cannot be represented using rectilinear objects. The processes have been shown to work for examples based on both notional and real complex obstructions and the case study has demonstrated its potential use in the modelling, modification and evaluation of alternative installations configurations.

It is clear that a considerable amount of effort is involved in the collection and processing of images to produce usable models at the moment. Whilst the current techniques could be used as a research tool to model existing obstruction for light loss calculations it would not be an economic proposition for use in the majority of situations, but for those with hazardous environments such as heavy industrial plants (where working plane illumination is critical for safe operation) the extra work is acceptable to produce a safe and environmentally sustainable solution. This is an area on which we will be expanding in future work.

As digital photography and photogrammetry software develops the amount of manual input required should be able to be reduced to a point where the use of photogrammetry in interior lighting design could become more commonplace.

References

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