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Holography: Art and Science of Light in Architecture

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Holography provides a medium for creative visual experiences in space and scale. It has been firmly established as a tool for scientific and engineering studies. It could be creatively used in architecture and building design as a practical device and as a form of art. Basic principles and features of holography are explained. Designs of the holographic systems are illustrated in some architectural applications. It is believed that holographic elements can make a valuable contribution to architectural design by controlling light and creating new concepts of colour and space.

Introduction

Holography is the process by which three dimensional visual information is recorded, stored and replayed. The Greek word 'holo' means whole, complete and 'gram' means message. A holographic picture has 'parallax' (the ability to see a scene from many angles) and depth of field which allows a multi-dimensional image to be displayed under proper illumination. Nowadays, holographic elements can be found in our everyday life, such as the foil stamps on credit cards and the optics in supermarket scanners. Holographic technique is commonly used by the publishing, advertising, and banking industries because holograms are eye-catching and can prevent counterfeiting.

Technical applications of holography are represented through holograms used in medicine, engineering and retailing, for example, for non-destructive test and inspection using holographic interferometry [1]. The techniques of optical holography are now firmly established as a display medium as well as tool for scientific and engineering studies [2]. As holograms can give an illusion of depth, they can be used as a visual medium for producing high-quality spatial displays for complex 3-D information, for automotive design, medical imaging, scientific visualisation and advertising.

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Holography can also be used as an art form or medium [3]. Although the domination of abstraction is evident in the portion of the collection devoted to holography as art, the full range of artistic possibility is apparent in the works of such internationally-recognised holographers as Margaret Benyon, Rudie Berkhout, Sally Weber, and Dan Schweitzer. Holographic studios in some parts of the world record holograms of art work from collection and museum articles. Display of art objects or commercial products by using holography can avoid theft and allow new dimensions of creativity. Unfortunately, the 3-D effect of holograms cannot be shown here by ordinary printing methods, but you can experience a holographic image easily on the foil stamp of the credit cards in your pocket.

Application of holography in architecture and building design is now still very limited [4, 5]. Holography has become interesting for architecture not only because of its paradoxical representation of the 3-D space, but also for its physical characteristics, dispersion and diffraction of light. Holographic films, known as 'holographic optical elements' (HOEs), can be laminated between two glass panes and used for various applications in architectural design. Research studies by Müller [6] showed that HOEs can be used to improve daylighting quality in buildings and allow a better utilisation of solar energy. Holography also opens up new possibilities in architectural and interior designs by acting as information guide in public space and creating three-dimensional images for architectural presentation [7]. This paper explains the basic principles of holography and describes its practical uses in architecture. It is hoped that more people will understand holographic technology and will be able to make use of it for creative and useful purposes in building design.

Principles

A *hologram* is a photographic film or plate which has been exposed to laser light and processed in such a way that when illuminated appropriately it produces a three-dimensional image or special colour effects [1]. The theory of holography, also known as 'wavefront reconstruction', was first developed in 1948 by Dennis Gabor, a Hungarian physicist who was awarded a Nobel Prize in physics in 1971 for his invention of holography. Holograms are made using precision optical instruments and special photosensitive materials, which are exposed with laser light. The special light sources for viewing are monochromatic (single color) in the case of transmission holograms. Optimum viewing conditions for this type of hologram are often by means of a laser in a darkened environment. Some holograms must be viewed with laser or monochromatic light and others with white light.

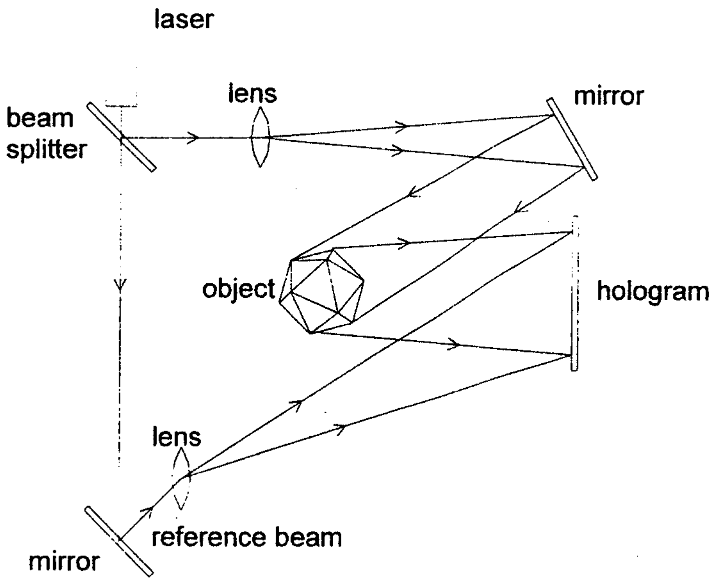

Fig. 1. Recording stage of holographic process

Holographic Process

A brief account of the holographic process is desirable for understanding the basic technique [3]. To make a hologram of an object, a laser beam is split into two and both beams are spread out by a lens (Fig. 1). One beam, the reference beam, falls straight onto the holographic plate; the other, the object beam, falls onto the object and the light is reflected onto the plate. The holographic plate is photosensitive and records the interference pattern from the two beams falling onto it. The plate is then processed like an ordinary photographic film. The interference pattern allows a record to be made of the detailed properties of the light reflected from the object, that is, the phase relations to which the plate is not sensitive as well as the intensity to which it is. The laser light used is coherent, that is, the light waves are in phase, so that the crests or troughs in the waves all travel along together. The random wavefront from the object meets the coherent wavefront from the reference beam at the plate and they interfere to produce a pattern of light and dark according to whether the waves are in or out of phase.

To view a hologram (Fig. 2), the plate is illuminated with a spread laser beam or reconstruction beam directed at the plate at the same angle and distance from it as the original reference beam. The reference beam acts as a sort of coder and the image is decoded by the reconstruction beam. The light is diffracted to produce a 3-D image of the same size as the original object. The interference pattern in the emulsion directs some of the reconstruction beam to travel on, as did the light from the object in the first instance. To the eye there is no noticeable difference between the image and the object.

There are several types of holograms in the market. *Transmission holograms* are viewable with laser light and they are made with both beams approaching the film from the same side. *Reflection (white light) holograms* are viewable with white light from a suitable source such as spotlight, flashlight, or the sun, and they are made with the two beams approaching the holographic film from opposite sides. *Multiple channel holograms* allow two or more images to be visible from different angles and images can be combined to create animation or special colour effects (such as multiplex and rainbow holograms). *Real image holograms* are reflection holograms made from a transmission original; the image dramatically projects in front of the plate toward the viewer and most holograms in holography museums are of this type.

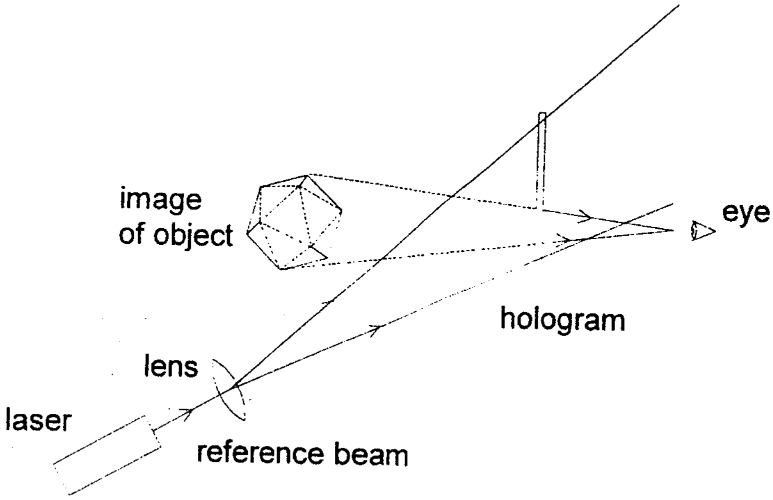

Fig. 2. Reconstruction stage of holographic process

For large runs of holograms to be produced in a cost-effective manner, a method has been developed to emboss complex microscopic patterns onto rolls of very thin plastic or foil materials. Light interacts with these patterns to create the holographic (reflection) image. Embossed holograms are mass-produced holograms often seen in printed products but they are limited in size and quality. Holograms made in small scale from polymer and dichromates are used instead for high quality results.

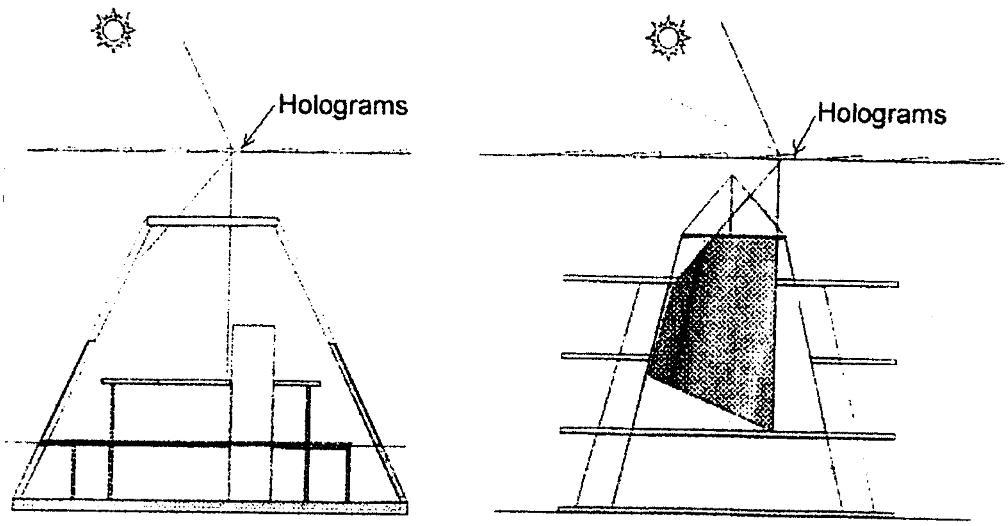

Fig. 3. Display holograms at the Academy Mont-Cenis in Herne, Germany

Holographic Optical Elements

The principle of HOE is the diffraction of light by gratings and zone plates. Traditional optical elements use their shape to bend light. HOEs work by breaking up incoming waves of light into a large number of waves, which recombine to form completely new waves. HOEs can function as gratings, lenses or any other type of optical element. Large optical apertures, lightweight and lower cost are the main features of HOEs. They can also offer unique optical properties that are not possible with conventional optical elements.

HOEs are wavelength sensitive: the focal length and aberration characteristics of the element vary with wavelength. They can also be made to operate over a narrow wavelength band. Several different optical elements can share the same substrate without interfering with one another. Thus, a single HOE can be used as a lens, beam splitter and spectral filter simultaneously. HOEs can duplicate most of the functions provided by glass optics if the optical system operates over narrow spectral bandwidth or requires chromatic dispersion.

From the architectural point of view, HOEs have certain useful properties for light transmission and radiation control. Unlike conventional optical elements such as lenses and mirrors, HOEs are flat, lightweight and easily stackable. If designed and integrated properly, they can be used to control, focus and select light so that the lighting and thermal performance in the built environment can be improved. Another advantage is that the HOE systems usually have no moving parts and require low maintenance.

Practical Applications

Some practical uses of holograms in architecture and building design are presented (they have been built and studied in the building projects in Germany). The holograms are fabricated on thin foils which are laminated between glass panes to protect the emulsion material.

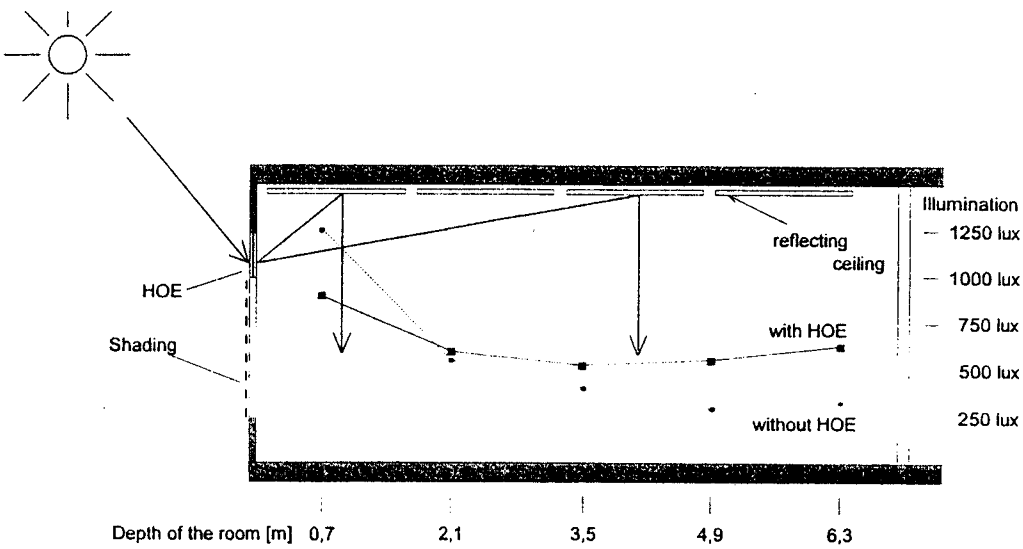

Fig. 4. Light guiding HOE system with ceiling reflector

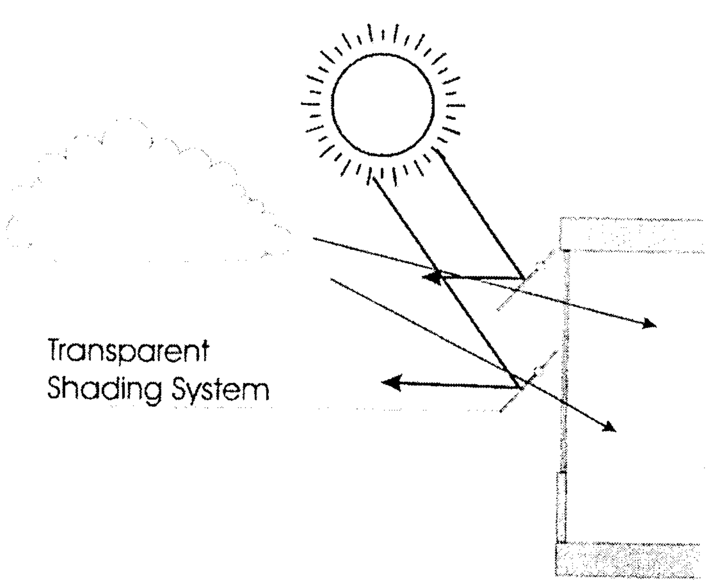

Fig. 5. Transparent shading system using HOE

Holographic Displays

Holographic diffraction gratings show a similar effect as prisms. White light is split into the rainbow colours of the spectrum after passing through the gratings. This effect can be used to create display lighting and colour effects in glass façades or skylights. In the daytime, direct sunlight is used to illuminate the display; at night and for overcast sky conditions, artificial light is used. As HOEs have a limited active angle, they can only be seen from a certain range of viewing angle (maximum range about 60 degrees). By changing the position of the light source or the viewing angle, the colours of the display will vary.

Fig. 3 shows an interesting example of the use of holograms for colour or display purpose in the Academy Mont-Cenis in Herne, Germany. The building is an innovative, energy-efficient greenhouse structure with extensive use of glass in the façades and roof (it won the European Solar Prize 1999). The holograms are put on the skylight of two coned-shaped structures inside the building – a library and a lobby. Photovoltaic cells are also installed on the roof and some wall surfaces. A kaleidoscope of colour is created on the floor when direct sunlight is falling on the holograms.

Light Guiding

HOEs can be used to create holographic windows for daylighting applications in buildings [4]. The function of HOEs in daylighting applications is to redirect sunlight from the immediate window area into the rear of a room so as to illuminate the darker regions and to reduce glare. An important condition for the successful application is the solution of the problems of white light diffraction and of uniform holographic properties across a large aperture.

Fig. 4 shows a light guiding HOE system with ceiling reflector. The incident light from a certain angle of the diffuse sky is diffracted by the HOE grating and guided to the ceiling of the room which has reflective surfaces. Due to the different angles of the light, the colour dispersion is remixed and only small colour effects occur. If properly designed, direct sunlight falling onto the HOE grating can also be guided to the ceiling to provide even illumination in the indoor space. The daylighting design has been integrated with the control system for electric lighting to reduce energy consumption and provide adequate illumination as required.

Sun Shading

HOEs can be used in sun shading systems to block direct sunlight and allow the penetration of diffuse light for illuminating the interior space (Fig. 5). To provide good visibility or view, the level of transparency of the HOE can be controlled by designing the active angle of the element. Usually the HOE glasses can be looked through except of the direction of the active angle in which only a small portion of direct solar radiation is transmitted. They can be installed at a fixed position or to move around the horizontal or vertical axis, either in front of a façade or over a glass roof. Solar tracking is also possible. The system is most effective when the diffuse light is coming from the zenith region of the sky. The holographic sun shading system can be designed in different forms and shapes. It can also be integrated with other building elements or energy systems, such as photovoltaic cells.

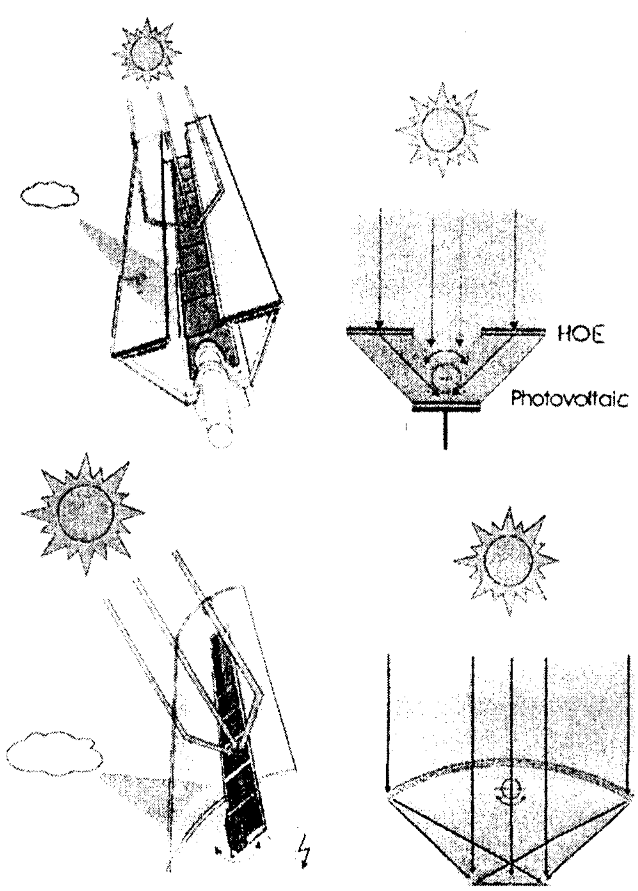

Fig. 6. Concentrating HOE and photovoltaic cells

Photovoltaic Integration

The use of photovoltaic cells as opaque elements placed behind the HOEs may allow generation of electrical energy from the component. This achieves a double effect: the energy output of the solar cells is increased while the focussing of the light onto the solar cells impervious to light results in a shaded room and thus prevents its overheating. There are different forms of transparent shading devices integrated with concentrating holograms and photovoltaics [8]. Fig. 6 shows two types of the designs. The HOEs redirect the perpendicular incident light onto the opaque stripe on the lower surface and block direct radiation or heat transmission. The HOEs are inactive for all other angles of incidence so that diffuse light can pass through the element for illumination purposes. The view out of the building is only affected by the opaque stripes (30%-50% of glass area), the HOE parts are almost completely transparent.

Future Prospects

Today, many laboratories and studios possess the necessary equipment for making holograms: a continuous wave laser, optical devices (lens, mirrors and beam splitters) for directing laser light, a film holder and an isolation table on which exposures are made. Stability is absolutely essential because movement as small as a quarter wave-length of light during exposures of a few minutes or even seconds can completely spoil a hologram. At present, a lack of suitable recording material has made hologram production and replication difficult. The production cost of transmission holograms is relatively high and the basic off-axis technique is still most commonly found for the holographic methodology. Growing interests in holographic technology is leading to a demand for better research and cost-effective production of HOEs. Development of holographic applications in architecture will depend on the economic factors and the creativity of the designers.

Holographic Research and Production

With the advent of low cost laser diodes, holographic research and production is becoming easier and less expensive. Gale [9] pointed out that development of replication technologies for holograms would allow mass production of a large area, complex microstructure by low cost, high volume industrial production processes. Industrial fabrication of large format HOEs would lead to better opportunities for architectural applications [10]. The accomplished technology facilitates the continuous fabrication of the holographic films on glass or plastic substrata. In this particular case, the HOEs (reflective or transmissive) are recorded in dichromated gelatin layers deposited on glass or plastic substrates. This material and the corresponding thermochemical development process facilitate the achievement of bandwidths, spectral ranges and angular selectivity that match accurately the design spectral and geometrical properties of a particular application. It is believed that bandwidth and angle selective holographic films can be produced accurately for specific architectural or solar energy applications [11].

Future development in holography in other fields could have significant implications to architecture too. For example, computer-generated holograms of hypothetical objects would provide an interesting way for space definition and representation. True color holograms (introduced in 1994) are already creating new applications in many areas of science and industry. Holographic movies and sound-recording holograms (with sound to be read out with light) are being developed in media research laboratories as an intelligent storage medium. If these techniques can be applied in architecture, it would bring new concepts of space, light and form.

Architectural Integration

Architecture is the field where technological and aesthetic qualities of holography can be expressed in a most significant way [7]. For example, in the field of communication displays and interior design, an innovative relation between light and the surrounding space can be created by using holography in interior lighting. Vito Orazem has created some lighting installations for exhibitions using this technique.

The applications in this papers represent only a few possible areas which holography can be utilised in architecture. With the help of HOEs, the management of daylight and the design of windows can be approached from a different perspective. More research is needed to study the characteristics of the holographic elements and integrate them into the building systems and components.

Holograms can extend and expand the scope of visual presentation. With holography it is possible to record things invisible to the naked eye or turn space 'inside-out'. The possibilities of holography on an architectural scale are yet to be discovered. Innovative ideas, such as using holograms as information guide in public spaces or as light wall for design and presentation, will open up new areas for creative architecture and interior design.

Some of the problems inherent in integrating holograms into an architectural context will need to be solved. For example, the function of holograms is limited by colour dispersion; present limitations on the size of holograms are too restrictive and the brightness of holographic images is often too low. It is envisaged that development of holography in the future will provide more opportunities for architectural application.

Conclusions

Holography provides a medium for creative visual experiences in space and scale. It could be creatively used in architecture and building design as a practical device and as a form of art. Study of the scientific principles and techniques in holography will help in understanding the features and potentials of holographic methodology. Possible designs and benefits of the holographic systems are illustrated in some practical applications in display and daylighting design. Future development of holographic research will provide opportunities for architectural application which will bring new concepts of space and light. More studies and innovative ideas are needed to investigate this interesting 3-D medium.

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