

Use of 3D-Printing Technology in Architectural Research

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Abstract

Daylighting studies rely on simulations and experiments to assess the performance of a particular daylighting system. To this end computer models using coding systems are either too complex or are limited to only some daylighting simple systems or devices. One of the technologies that have made customization a reality is 3D printing. This technology permits the building and experimentation with various devices needed to assess the performance of daylighting systems rather quickly and cost effectively. This paper seeks to examine the use of 3D printing in Architectural Daylighting Research and discusses some of the future trends that will make this technology more cost effective.

Keywords: 3 D printing, Daylighting, Architectural Research.

1. Architectural & Daylighting Research

Daylighting studies rely on computer simulations (Ignacio, et al., 2011) and experiments (Chiara & LoVerso, 2008) to assess the performance of a particular daylighting strategy. Computer models are generally available for simple daylighting systems, such as simple shading devices, light shelves (Fig. 1), simple skylights (Fig. 2). Computer codes that are able to assess the performance of more complex systems have been developed over a period of many decades of experimental and theoretical studies. (Ubbelohde & Humann, 1998; Reinhart & Andersen, 2006). They are also often not very easy to use, requiring expertise on the part of the user to be able to input the data and analyze the output information. Also these computer codes cannot analyze many of the available daylighting and optical devices for lack of theoretical algorithms governing their daylighting performance.



Figure 1: Section drawing of a light shelf system.

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Figure 2: Simple skylight system at Zurich Airport

With more complex systems experimental studies are needed. These experimental studies often use scale models or full size mock-ups. Scale models are fast and fairly economical to build. They can be tested under artificial sky simulators, allowing, henceforth, higher degree of control of the extraneous variables while insuring conditions of reproducibility, a necessary condition for any scientific study. Scale model studies can also be used under real skies offering, as a result, more realistic scenarios. They are, however, limited by the ability of the researcher to reproduce the interior and exterior conditions of a room or a building. Moreover, it is not always possible to reduce the size of a particular daylighting device or optical system to fit the scale of the model. These are practical and economical disadvantages often encountered in scale model simulation in architectural research. The inability or impracticality to model accurately the conditions of a room or a building generally creates a large discrepancy between the simulated and the real environments.

There are many examples of daylighting systems where it is not possible to test a wide range of variables of the particular system. For example, prismatic panels may be used in conjunction with side windows to deflect incoming rays of light upwardly towards the ceiling of a room (Fig. 3 & 4). The geometry and the angles (vertices) of the prism dictate the extent of the sunlight deflection as shown in Fig. 3, 4 & 5, and consequently the performance of the daylighting system itself (Boubekri, 1999). As demonstrated in Boubekri's study, the researcher was able to test only the shapes and angles of the prism configurations available on the market (in this case 45° and 60° angles). This practical reality hindered the researcher to test a wider range of prism vertices and limited to extent to which the study could be generalized. Testing a large number of angles for the prism would allow the research to optimize the angle of the prismatic panel according to seasonal changes of sun angles and according to locations.

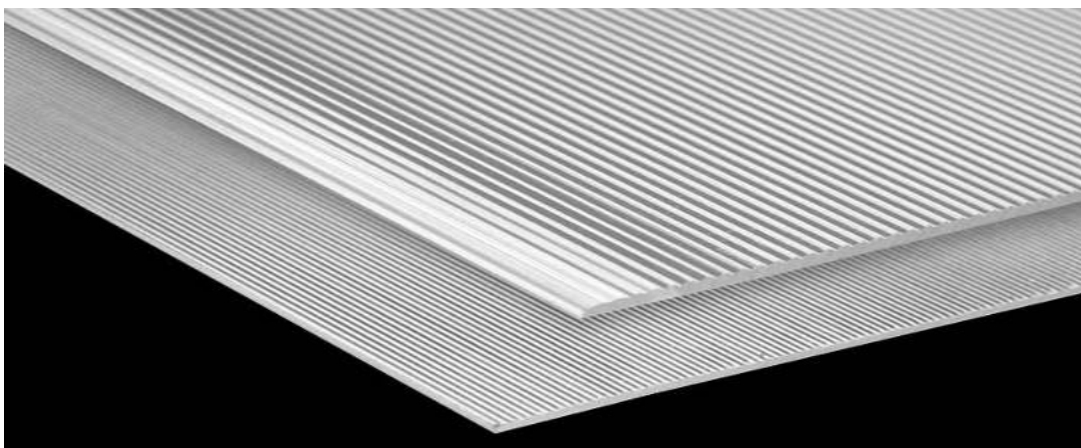


Fig.3 Acrylic prismatic panels used as side-daylighting systems

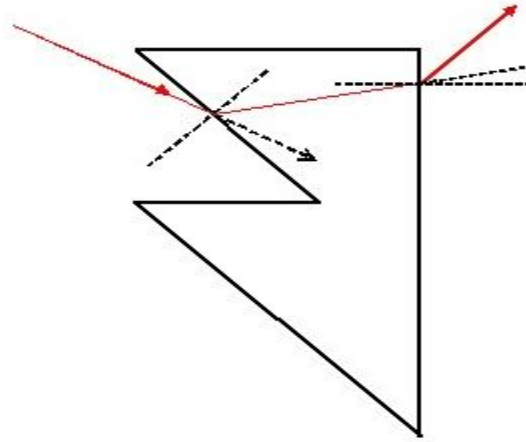


Fig.4: Daylight deflection with a prism.

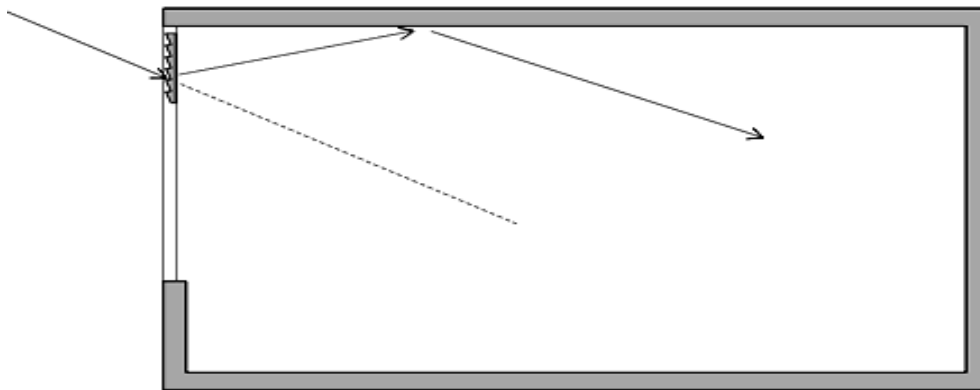


Fig. 5: prismatic panels as side-daylighting strategy.

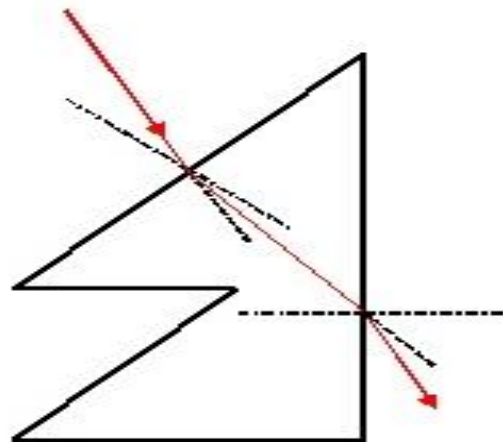


Fig. 6: Prismatic panels as shading strategy.

Other daylighting systems fall within the same types of limitations mentioned above. For example special louver systems have been used as systems that deflect light upwardly toward the ceiling and consequently towards the back of a room increasing henceforth daylight levels in that portion of the room (Fig. 7, 8 & 9). In this case, the combined effect of the size of the louvers, degree of curvatures, and spacing between the lamellas have a substantial impact on the performance of the system.

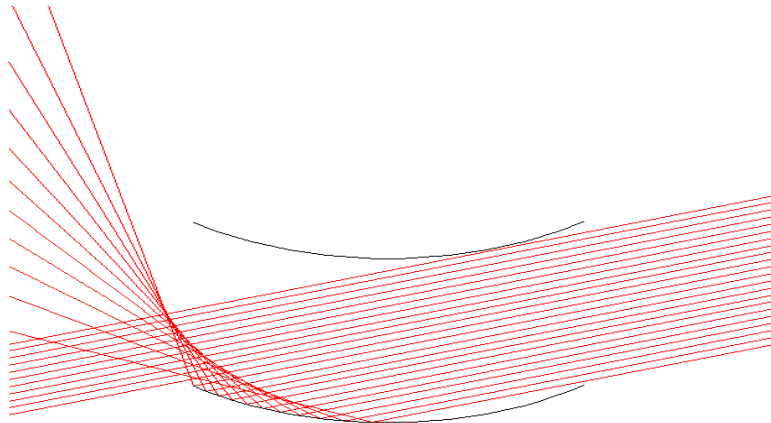


Fig.7: lamellae louver system

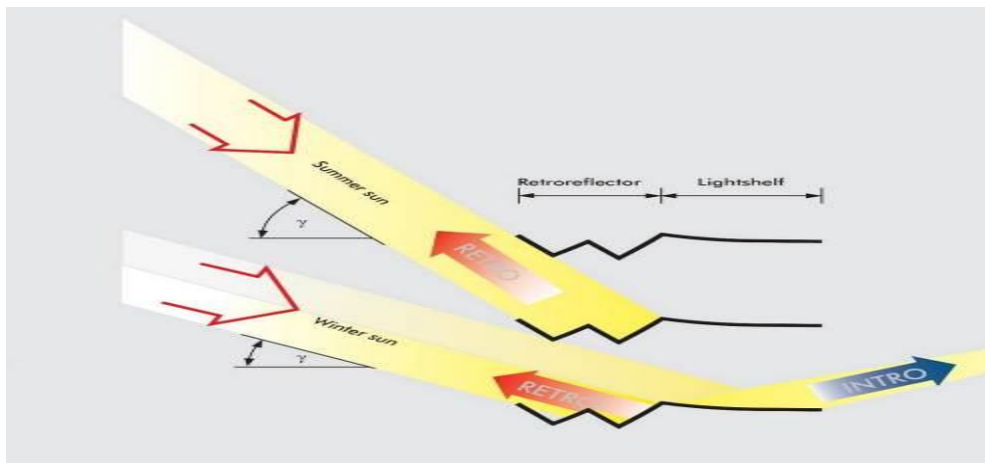


Fig. 8: Solar controlling louver daylighting system



Fig.9: Fish louver system by Lightlouver Inc.™

Scalemodel simulations rely on scale reduction; however, many of these daylighting systems cited above may not easily be scaled down to smaller sizes in order to be fitted and tested in scale models. Researchers rely sometimes on full-size mock-ups to test many such systems that cannot be scaled down. While full size mock-ups eliminate the problem of scale, they are not used too often because of cost limitations. Full size mockups are generally tested under real skies only, not in artificial controlled skies (Fig. 10). With full-size mock-ups it is not always possible to test a large degree of variability of certain features of the device such as reflectance values, curvature, etc. because of cost limitations. Consequently, the ability to optimize performance and generalize the outcome of mock-up studies is limited. Because of a loss of control of the exterior conditions, ideally researchers would be better served if they could test many of these daylighting systems under controlled sky conditions if they were able to use scale model and scale down many of these optical and daylighting devices they are investigating. As mentioned previously, scale models offer also the economic advantage as well. Recent technological development in 3D-printing offer such possibilities.



Fig. 10: Full-size Mockup testing daylighting louver system.

2. 3D-Printing Technology

3D Printing commonly referred to as additive manufacturing, is a collective term for technologies that permit the production of physical goods from the bottom up. While traditional tools for fabrication like lathes, drills and saws use a large piece of raw material and trim it to create a shape (subtractive manufacturing), 3D Printing does the opposite. Raw materials are added, a single layer at a time and ultimately an entire object is fabricated based on a digital design file that contains the information about the desired object (Lipson & Kurman, 2013.) 3D Printing is a manufacturing technique that permits intricate designs to be produced as may be required by some daylighting technologies. In the case of acrylic prismatic panel testing it would be fairly easy and economical to produce 4 or more different versions of the prismatic panel that the researcher may want to test such as is shown in figure as a matter of illustration (Fig. 11). In other instances, not only the side, shape maybe easily changed but also the materiality of the device as well. In the case of louver system shown in figure 8 or 9, the system maybe made any number of materials ranging from aluminum to acrylic or any number of other possibilities (Fig. 12). These possibilities allow the researcher not only to test a number of design options quickly but also weigh in factors such as cost, durability, maintenance etc.

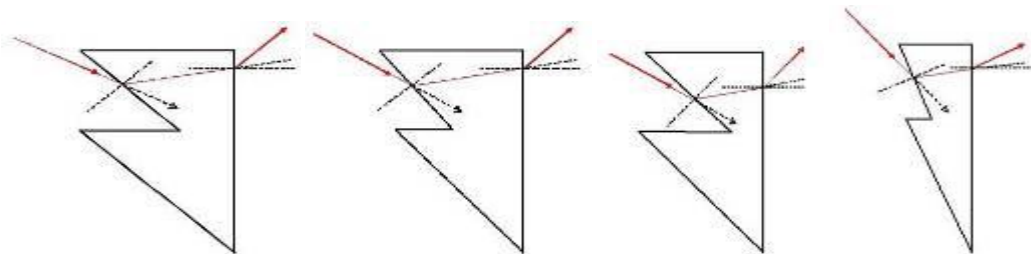


Figure 11: Prismatic acrylic or glass panels with 4 different prism vertices.



Fig. 12: Quick customization in shape, size and materiality of a special louver system for solar and daylighting control.

Historically, technological developments and advances have been the main reasons why we are seeing so much progress in design paradigms that promote building occupants comfort and wellbeing. Architects are always seeking for ways to optimize their designs and adapt them according to climate and building users' needs. Customization and adaptation is the new design paradigms that are today at the forefront of architectural research. 3D printing technology is an avenue available to researchers and designers to utilize devices that can be produced economically, allowing henceforth building skins to adapt to the exterior environment. For the sake of illustration, the SparkasseFürstenfeldbruck office Building in Fürstenfeldbruck, Germany (Fig. 13, 14 & 15) uses prismatic glass panels on the outside of the curtain walls of the building for daylight and solar control. In order to adapt to outside changing conditions of solar angles, these panels maybe rotated to let daylight in during winter and spring seasons or act as shading devices in the summer months. With 3D customized prismatic panels, the optimization of such system would have been maximized.



Fig. 13: Exterior façade of the SparkasseFürstenfeldbruck office Building in Fürstenfeldbruck, Germany.



Fig. 14: Detail photo of the rotating prismatic panel's on the façade of the SparkasseFürstenfeldbruck office Building in Fürstenfeldbruck, Germany.



Fig. 15: Daylight deflection inside an office of the SparkasseFürstenfeldbruck Building, in Fürstenfeldbruck, Germany.

3. 3D-Printing Advantages

3D Printing offers numerous advantages over traditional manufacturing.

a) Economic effectiveness: 3D Printing is often found to have potential in terms of achieving the direct-cost standards associated with traditional manufacturing particularly for low to medium levels of production and when dealing with intricate parts or systems' designs (Hopkinson & Dicknes, 2003; Eleonora et al., 2010 & Sculpteo, 2015)

b) Less material waste. Machining metal under traditional manufacturing generates a significant amount of material waste. However when using 3D Printing technology, only the amount of raw material necessary is used in the fabrication of the intended product. This result in a lesser carbon foot print and has a great positive impact on the environment (March, 2012).

c) No tooling costs: An important component of 3D printing is the technology's ability to reduce or eliminate tooling (Jens et al., 2012). Among the costs associated with tooling are maintenance, storage, and tracking over a prolonged period of time. All these costs are virtually eliminated with 3D printing technology.

d) Smaller Production Runs: Anderson notes that 3D printing offers a perfect solution for manufacturing small quantities (Anderson, 2012). The technology also provides a manufacturing technique to fabricate unique products. Architectural research performance analysis studies require testing different strategies using different devices that may requires different and intricate shapes difficult to model mathematically or through computer simulation.

e) Large Scale Customization. In the world of 3D printing, variety and complexity can be realized fairly easily. The cost associated with manufacturing ten different items is the same as the cost of manufacturing ten identical items. Similarly, the cost of fabricating a highly decorated ornament is the same as that of printing a solid plastic item (Anderson, 2012). The characteristic associated with 3D printing permits mass customization. In the case of daylighting systems, their performance is always dependent on sun angles and consequently on the changes of the seasons. Large scale customization allows daylighting systems to adapt to the changing conditions. Moreover, rooms inside buildings are not always equal in size.

Ceiling heights and room depths maybe different within the same building and among different buildings. 3D printing production allow quick testing and quick adaptation of the daylighting system to the changing conditions inside and outside a building without occurring significant high costs in production in standard manufacturing modes.

4. Future Developments

Although some form of 3D Printing technology (Stereo Lithography, Fusion Deposition Modeling) existed since the early eighties, its adoption rate has been relatively slow. There are numerous trends in the 3D printing technology, however, that will make it more cost effective in a variety of industries and, hence, more feasible including research and mass customization in architecture.

- a) Increased adoption of blue-ray diodes: A significant percentage of the cost of 3D laser printers is in the laser modules. However, over the recent past, there has been an explosion of Blu-ray players. As this trend continues, the cost of laser modules will be significantly brought down. Blu-ray diodes are currently available at a relatively lower cost. This will permit the production of desktop systems targeted for consumers.
- b) Protection of STL File Format: 3D printers largely depend on digital files, which represent the designs to be printed. One of the main problems in the industry the copyright or ownership rights of the designs. At present, consumers can purchase STL (Stereo Lithography file format) from numerous online libraries at a cost of \$40 or \$50. High-end sculptures cost as much as \$600 per print and as high as \$2,000 or more. Currently, designers lack any form of protection. This is because there is no in-built mechanism to protect an STL file from being reused or even copied. Designers are hence forced to charge a higher price for their designs. However, this is set to change in the near future with protection mechanisms being thought. Purchase of designs will become widespread when marketed by a great vehicle such as Apple through impulse buying at a very cheap price. This will allow users to try different designs.

Some 3D printers are already designed with a touch screen. This permits the design library to operate using the 3D printer alone without the need for a personal computer, which reduces the costs associated with 3D printing. Once an online store is created, it will work in the same way Amazon operates. It will serve as a marketplace that connects design developers and design buyers. Some 3D printer manufacturers such as FSL3D are already developing printers with in-built digital rights management (DRM). Each printer is encrypted to a single serial number. Using such 3D printers, designers are able to sell their designs to anybody with DRM 3D printers and the design can only work on that single printer. This eliminates the risk of designs being stolen or copied endlessly between printers. The lower prices will significantly boost adoption rates by permitting more designers to become part of the ecosystem. Furthermore, many professional designers are also sharing their designs free of charge in order for users to provide feedback for design improvements.

- c) Expiration of Major Patents: Major patents that for decades have prevented competition in the industry have started to expire. These patents have protected the laser sintering technology. Following the expiration of key patents associated with 3D printing technology, the industry will see a significant drop in the prices for 3D printing devices. A similar trend was observed when major patents for fusion deposition modeling (FDM) expired with a significant increase in open-source fusion deposition modeling printers. Within a few years after the FDM patents expired, the prices for FDM printers dropped from \$14,000 to as low as \$300. This resulted in a significant democratization of consumer-level 3D printers. A similar trend is expected with laser sintering technology printers.
- d) The Emergence of Consumer level 3D Printers: The market for consumer level 3D printers did not exist before the year 2000. However, the efforts made by DIY hobbyists and enthusiastic tinkerers (maker movement) are changing the industry landscape. These groups have developed significant interest in the 3D printing technology and have become part of the web generation. They share ideas, designs, and knowledge in a prompt manner and collaborate with other similar-minded groups and individuals in specialized online communities, fab labs, and hacker spaces as noted by Anderson (8). Because of their efforts, the prices for 3D printers will drop significantly in the future because as they open-source the hardware, many more players specializing in consumer-level 3D printing will join the industry. The efforts by the maker movement have also compelled companies in the 3D printing business such as Stratasys™ to begin focusing on the consumer market (Morgan Stanley, 2013; Moilanen, 2015 & PWC,2014)
- e) Entry of new players. Hewlett Packard (HP) has already declared its intention to enter the 3D printing market by 2016. Even though the company will focus on high-end professional 3D printing devices, its entry into this market will make the technology more established and enhance its credibility in the eyes of consumers. In addition, given HP's financial resources, the company is able to invest significant resources in research and development (R&D) and capitalize on its existing manufacturing plants to drive down the prices for 3D printers thereby reducing the barriers that has prevented users from adopting the technology. This trend may also encourage other technology companies to join the market, leading to more competition and driving down.

5. Conclusions

There are numerous economic benefits that come with 3D printing technology in wide range of fields of architectural research. To begin with, most devices that can be drafted using CAD software can theoretically be manufactured quickly and cost effectively with 3D printers. This presents a huge practical advantage for daylighting investigations as well as many other types of empirical architectural investigations. Secondly, it leads to reduced waste of raw materials compared to traditional manufacturing. Thirdly, unlike traditional manufacturing that relies on large-scale production to offset costs, 3D printing is very economically feasible for smaller production runs or large-scale customization including the production of very intricate, difficult or impossible to make products using traditional manufacturing techniques. The industry is taking a number of initiatives that will make the technology more cost effective. These include increased manufacturing and use of Blu-ray diodes to replace laser modules. Another initiative is the protection of STL File Format to reduce piracy and reuse of designs and reduce the price for the final product. Similarly, the expiration of patents will see an increase in open-source 3D printers that will drive down prices. Other initiatives include the entry of new players in the industry such as HP, the proliferation of consumer level 3D printers and recycling opportunities that will reduce the costs associated with owning a 3D printer.

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