"Seeing" with the hands

Teaching architecture for the visually-impaired with digitally-fabricated scale models

Gabriela Celani[1], Vilson Zattera[2], Marcelo Fernandes de Oliveira[3], Jorge Vicente Lopes da Silva[3]

[1] Laboratory for Automation and Prototyping for Architecture and Construction (LAPAC), University of Campinas, Campinas, Brazil
celani@fec.unicamp.br
[1] Institute of Arts (IA), University of Campinas, Campinas, Brazil
vilson.zattera@gmail.com
[3] 3D Technologies Division (DT3D), Renato Archer Information Technology Center, Campinas, Brazil
{marcelo.oliveira, jorge.silva}@cti.gov.br

Abstract. Accessibility of information for the visually impaired has greatly benefited from information and communication technologies (ICT's) in the past decades. However, the interpretation of images by the blind still represents a challenge. Bidimensional representations can be understood by those who have seen at least sometime in their lives but they are too abstract for those with congenital blindness, for whom three-dimensional representations are more effective, especially during the conceptualization phase, when children are still forming mental images of the world. Ideally, educators who work with the visually-impaired should be able to produce custom 3D models as they are needed for the explanation concepts. This paper presents an undergoing project that aims at developing a protocol for making 3D technologies technically and economically available to them.

Keywords: Tactile models, rapid prototyping, architectural concepts.

1 Accessibility of visual information for the visually impaired

Since the use of computers is based on a visual interface, its use by the visually-impaired has never been a trivial thing. Only in the 1980's screen reading programs started being developed. This type of software can interpret what is displayed on a computer screen and produce a sound output using speech synthesis technology, or send text information to a Braille output device. However, images inserted in a text file cannot be recognized by it.

The importance of images in the contemporary world has progressively increased with the availability of large amounts of information. The fact that many scientific journals now display a "summary image" along with papers' abstracts is an example

adfa, p. 1, 2011.

of how images can be used to quickly inform lots of contents and transmit an idea that would take longer to explain with words.

While the transmission of information by means of visual material is a good thing for those who can see, for the visually-impaired it represents an extra obstacle on top of all the barriers they already face every day. This problem is usually overcome with the insertion of detailed textual descriptions of the images or photographs, which gives a rough idea of their content.

When a graphic embosser is available, line drawings can be automatically converted into tactile maps. The software that controls these machines allows automatic conversion of shaded and colored images to 3-D tactile graphics (see, for example, Able Data's Tactile Graphics Embossers). However, while simple drawings, such as diagrams and pie charts, can be easily understood through tactile maps, other types of images, especially perspective drawings and photographs, are too complex to be understood by touching a flat surface.

In the case of perspective drawings, the reason is simply because blind people are not used to seeing in the same way as people who can see with their eyes. Let´s take as an example a simple perspective drawing of a box (Figure 1), adapted from a book for visually impaired children. The book is written in Braille, with embossed images. Although a perspective image like this is very easy to understand by someone who can see with his or her eyes, a blind person could never guess that this is a rectangular box, unless someone told them so. For them, there is no rectangle in this image; just a pair of trapezoids.

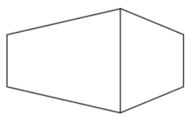

Fig. 1. A perspective drawing of a box, adapted from a book for visually-impaired children

Perspective drawings reproduce the type of image that is projected inside our retina by the light rays coming from the object and passing through our pupil. The farther an object is, the smaller the incident angle and therefore the smaller the image in the retina (Figure 2). That is the reason why the closer edges of the box look bigger and the farther edges look smaller, thus making a perfectly rectangular object look deformed.

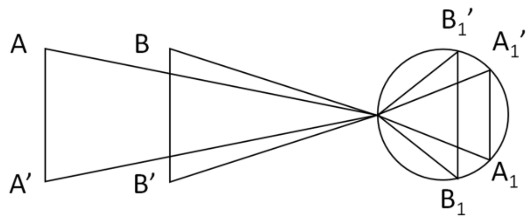

Fig. 2. Diagram showing why the closer edges of the box look larger in the image projected in the retina, while the farther ones look smaller, resulting in a distorted image

For a person who cannot see by means of light rays projected into his or her retina, this type of image is just not useful at all. A simple two-dimensional rectangle would probably be more helpful in explaining the idea, but it would not be capable of showing the third dimension. The comprehension of complex objects through two-dimensional drawings, even when accompanied by textual descriptions, is also extremely limited due to size limitations of what the fingers can sense.

Another interesting example is the fact that people who can see with their eyes represent the sky "touching" the sea in the horizon in landscape drawings. Although the distance between the sky and the sea is huge (A-A') and constant, when it is projected in our retina (A_1'- A_1) it looks close to zero in the far horizon, because the horizontal distance from our position to the horizon is extremely large, resulting in a tiny retinal projection. For a person who has never seen with his or her eyes, a drawing showing the sky touching the sea simply does not make any sense.

In the case of photographs the difficulty is even greater. The reason is because a photograph is analog to the images that we see with our eyes. The light bounces on the objects in a scene and is reflected through our pupil and projected on our retina, at the back of our eyes. The retina contains millions of photoreceptors (light sensitive cells), some of which perceive brightness while others perceive colors. These cells convert the light into a stimulus that is sent to the brain so we can actually see an image. Similarly, a photograph is composed of tiny little dots (called pixels) of color with different brightness levels. Visually-impaired people cannot see colors or shades; they can only sense edges and surface textures. Therefore, simply converting a digital photograph to a tactile map in which the depth of each point is based on the brightness of each pixel simply does not make any sense for a blind person.

In this paper we describe a project that aims at developing a method for producing 3D materials for the education of visually-impaired children and teenagers, with the use of digital fabrication techniques. The project aims at making it viable for school teachers to digitally produce their own, custom pedagogical 3D materials, through an easy to follow protocol. Our initial object of representation will be contemporary architecture, because its shapes are very abstract and hard to describe, and 2D representations (both orthogonal projections and perspectives) would have all the problems explained above.

2 Tactile pedagogical materials

According to Soler (1999), multissensorial perception can help in the formation of concepts by blind people. Each sensorial channel is related to a type of perception; while vision is a synthetic sense, touch is analytic, because it allows perceiving a phenomenon through a series of concrete perceptions that allow sensing parts of the whole. Based on this observation, Ballestero-Alvarez (2003) emphasizes the reciprocal relationship between touching by hand and intellectual development.

Different types of tactile materials are used for the education and orientation of visually-impaired people. Tactile maps are commonly used to help the visually-impaired in building a mental image of the environment where they have to move around. According to Ungar, S., Blades, M. & Spencer, C. (1995) tactile maps differ from tactile models (also called tactile wall-maps) because the later are less abstract and more three-dimensional, showing spaces in scale, with low walls, and displaying architectural details (such as doors, windows and railings) and equipment (such as furniture and appliances). Tactile maps and tactile wall maps are especially efficient for adults with sub-normal vision, allowing them to quickly form a precise and complete mental image of a space. Some works (e.g. Ungar et al., 1996) show that the same result cannot be achieved through direct experience, because motion results in the loss of spatial references and therefore the loss of orientation.

Certain museums (e.g. Pinacoteca do Estado, 2013) use tactile materials for presenting artwork for the visually-impaired. These include low reliefs (usually digitally made) from 2D images of the paintings, and 3D scale models that reproduce the environment depicted in the paintings. Although these scale models are usually handmade and sometimes not very accurate, they are very efficient in explaining what is going on in the pictures for the visually-impaired.

Scale models can be also very helpful in the education of blind children and teenagers, especially in the case of congenital blindness, to help them form concepts about things they have never seen. Carney et al. (2003) acknowledge the importance of Concept Development in the education of the visually-impaired:

"A concept is a mental representation, image, or idea of what something should be. Students with low vision need assistance making the connection between vocabulary and real objects, body movements and abstract ideas. They often miss a lot of the incidental learning available through vision and frequently develop inaccurate concepts" (p.24).

However, in their Teaching Students with Visual Impairments guide, Carney et al. only mention the use of models once, suggesting that Science teachers should "use real life articles or models if possible". The reason is probably because models are expensive and difficult to produce and to keep updated, and teachers usually do not have the know-how for producing their own models as they need them. Moreover, the translation between 2D and 3D representations is not easy, and people who can see tend to simply emboss 2D drawings instead of substituting a drawing by a 3D model.

3 Digitally-fabricated tactile materials

Additive and subtractive digital fabrication techniques can be used for the production of tactile materials for the education of blind people with great precision and flexibility.

Celani and Milan (2007) have tested the use of Selective Laser Sintering (SLS) for the production of tactile wall maps. Further tests have been made with the Polyjet technology by the 3D Technologies Division at CTI Renato Archer (not yet published). These techniques allow including Braille characters on the surface of the models. They have a nice touch feeling and have been successfully tested by blind people. However, they are expensive and can only be produced with very sophisticated equipment. For that reason, CTI Renato Archer is also testing the use of open source 3D-printers for the production of low-cost tactile maps and possibly tactile models.

The production of embossed materials that can help the visually-impaired perceive 2D compositions, such as abstract paintings, may be successful in the case of abstract art, such as in the work developed by Aranda and Pupo (2011), for example. They used a function commonly available in CNC milling software for converting grayscale photographs of abstract paintings into low reliefs (Figure 3), which can be milled on different materials, such as wood and plastic. However, this technique is not efficient in the case of photographs or perspective drawings or paintings.

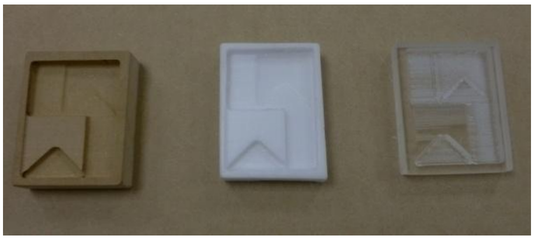

Fig. 3. Testing different materials for the production of tactile maps based on a painting by artist Alfredo Volpi (Source: Aranda and Pupo, 2007, p.282)

As 3D-printing machines are becoming economically accessible, it is possible envision their widespread use in schools for the production of custom-made pedagogical materials for the visually-impaired by their teachers. Another economically viable possibility is to produce tactile models with a laser cutter. This is possible by slicing the geometric model, sending each profile curve to a laser-cutter, and gluing together the slices to reconstruct the 3D volume. This operation can be facilitated by the use of open source, easy-to-use software that automatically slice a 3D model and layout the parts for cutting, optimizing the use of material. Parameters such as the material's size and thickness can be changed to comply with the available laser-cutter's power and bed size.

In this project we aim at developing a protocol for the production of 3D pedagogical materials for the education of blind children and teenagers by school teachers. The protocol will include the development of 3D-modeling skills and the operation of digital fabrication machines, as well as discussions about the best way to represent real-world objects for the blind. The project will start with a pilot program in which we will target specifically the representation of architectural objects.

4 Oscar Niemeyer's architecture

Oscar Niemeyer is probably the best known Brazilian architect in the country and abroad. In the 1950's and 1960's, he designed the all civic buildings in Brasilia, which became very famous. After that, he participated in projects and had buildings commissioned in different parts of the world, including New York and Paris. His use of reinforced concrete was highly influential on the architecture of the second half of the 20th century.

Since this 104 year-old architect passed away last year, a lot has been said and published about his buildings in the Brazilian and international press. Therefore, Niemeyer's architecture is an up-to-date subject that everybody is supposed to know about. However, his buildings are almost as difficult to explain as abstract sculptures. These are the reasons why Niemeyer's architecture represents a challenging, yet at the same time a pedagogically relevant, theme for this project.

A pilot test was performed in the production of conceptual tactile scale models of four buildings designed by Niemeyer: Saint Francis Church, in Belo Horizonte (1943), the Copan Building, in São Paulo (1966), the Museum of Contemporary Art in Niteroi (1996), and the Oscar Niemeyer Museum in Curitiba (2002). The buildings were modeled in CAD software and 3D-printed in ceramic powder, in a ZPrinter 310 Plus machine. All the models fit approximately in a 6x6x6cm box and are were 3D-printed as solids, because hollow models could be easily broken with the hands. They also do not include any small detail such as ramps or external stairways that could be easily broken by manipulation (Figure 4).

Fig. 4. Vilson Zattera removes conceptual architectural models (seen in on the screen) from a 3D-printer

The models were assessed by one of the authors of this paper, Vilson Zattera, who has been blind since childhood. The Saint Francis church model was used as a control variable, because that is the only building that Vilson has already visited among the four models produced. The test included meetings with High School teenagers, who were asked verbally describe the buildings to Vilson, based on photographs. These descriptions included vague statements, such as “it is a curved building” (referring to Copan building) or “it looks like a flying saucer” (referring to the museum in Niteroi). According to Vilson, the models can pass a good conceptual idea of the buildings. However, they could incorporate some level of detail through the use of surface textures that can be related to different building materials, such as glass and concrete.

5 Next steps

In the next step of this project we plan to develop a method for producing tactile materials with the use of digital fabrication techniques. As a pilot study, we will produce a series of tactile models for teaching children and teenagers about Oscar Niemeyer’s architecture. The project will be developed with the participation of high school teenagers and undergraduate architecture students, who will help in the development of the 3D models that can communicate the essence of Niemeyer’s buildings. Next, scale models will be produced with different economically viable techniques, such as layers of laser-cut material and low-cost 3D printers. Among the main challenges will be the incorporation of surface textures to represent different building materials and the use of production methods that are resistant but have a nice touch. These models will be tested with visually-impaired children and teenagers, both for cognition and resistance.

Based on that experience, we plan to set up a protocol for training school teachers who work with blind children and teenagers to develop their own tactile models using geometric modeling and digital fabrication techniques. Our ultimate goal is to develop a simple and economically viable protocol that can be used in public schools, so that any image material can be made accessible in 3D for blind students. This protocol will include the ability to develop 3D models or search for 3D models that are available for download on the web and the necessary skills to convert them from different formats into standard rapid prototyping file formats.

We expect that, by making this method available for school teachers, we can help introducing a new paradigm for the education of the blind, based in the possibility of producing custom 3D objects instead of adapting 2D materials, and thus helping in the formation of an image vocabulary, which is a fundamental step for the formation of more abstract concepts.

This project has been presented in an accessibility forum at the University of Campinas and for the municipal *Secretary for the Rights of the Visually and Mobility-impaired People*, in Campinas, and will be supported both by the University and the Municipality.

Acknowledgments

This project is supported by the following Brazilian public research funding agencies: FAPESP, FAEPEX, CNPq and CAPES.

References

1. Pupo, Regiane Trevisan, Aranda, Isadora Magdalena: Sentir um quadro [Feeling a painting]. In: SIGraDi 2011 [Proceedings of the 15th Iberoamerican Congress of Digital Graphics], pp. 281-284. UNL, Santa Fe, Argentina (2011)
2. Ungar, S., Blades, M. & Spencer, C.: Visually impaired children´s strategies for memorizing a map. British journal of Visual Impairment 13, 27-32 (1995)
3. Ungar, S., Blades, M. & Spencer, C.: The ability of visually impaired children to locate themselves on a tactile map. British journal of Visual Impairment 90, 526-535 (1996)
4. Carney, S., Engbretson, C., Scammell, K. and Sheppard, V.: Teaching Students with Visual Impairments: A guide for the support team. Regina, Saskatchewan: Saskatchewan Learning (2003)
5. Celani, M. G. C., Milan, L. F.: Tactile scale models: three-dimensional info-graphics for space orientation of the blind and visually impaired. In: 3rd International Conference on Advanced Research in Virtual and Rapid Prototyping (VRAP 2007), pp.1-10, Leiria, Portugal (2007)
6. Pinacoteca do Estado. PEPE Education for Special Public Program. Available at http://www.pinacoteca.org.br/pinacoteca-pt/default.aspx?mn=588&c=1049&s=0&friendly=programa-educativo-para-publicos-especiais---pepe. Acces in march 28 (2013)
7. Soler, M. A.: Didáctica multisensorial de las ciencias: Un nuevo método para alumnos ... Barcelona, Paidós Ibérica (1999)

8. Ballestero-Alvarez, J. A.: Multissensorialidade no ensino de desenho a cegos. Master degree thesis, University of São Paulo (2003)