Current and Potential Future Workflows of Digital Fulldomes

Muadh Al-Kabani and Cathy Easthope
Faculty of Technology, Engineering & the Environment,
Birmingham City University
Corresponding e-mail: cathy.easthope@bcu.ac.uk

Abstract: *The fulldome medium remains a leading technology in education and astronomy applications, yet it still fails to embrace different show genres that do not fall into these two categories. Standardization across all digital dome theatres worldwide is a task that is unlikely to happen due to the conflict in the fulldome community about the purpose of fulldomes. Even though distribution standards have been introduced, independent fulldome producers still face content creation challenges that start in early stages by the absence of fulldome courses in most educational institutions worldwide. Doubts about the possibility of digital domes becoming future cinemas are addressed by Hollywood movie producers that reiterate that fulldomes are built solely for educational purposes. Digital domes remain to be key educational tools at present, however if this medium is to be explored to its fullest, challenges facing the whole medium must be minimized if not eliminated.*

Keywords: Immersive, Planetarium, Fulldome, Digital Projection, 4K, Dome Master, 360 ◦, Opto-mechanical, IMERSA, IMAX, 3D.

Introduction

Digital projection technology has evolved rapidly over the years from the first desktop digital projectors, through its incorporation into Dome theatre (Planetariums) and into IMAX (image maximization) theatres, finally leading to the replacement of film in cinemas in general. We aim to analyse and investigate the current and possible future workflows of digital fulldomes, a relatively new means to project movies.
Technological developments resulted in traditional planetariums moving towards digital projection instead of the traditional optomechanical projection systems that lasted till the late 90s. This technological milestone in dome theatres changed methods of content creation, types of shows and the fulldome market. The purpose of dome theatres is becoming a more flexible video medium that openly projects any creative video or animation instead of being exclusive to astronomy and education.

Despite being around for 20 years and in almost every country around the world, standardization still does not exist in this medium. This abundance causes a significant conflict of interest between fulldomes worldwide. A conflict that is present due to the purposes of digital fulldome remaining to be undecided between traditional educational astronomy and the creative hidden potential fulldomes could offer.

Digital fulldome projection has a promising potential that is yet to be explored. This raises many questions about the obstacles that are preventing fulldome technology from becoming a

standardized medium for creative video production. Watching a full movie that has a storyline and is not educational or related to astronomy on a 360 degree screen has always been known as an interesting idea that is yet to be implemented.

Background

From a historical point of view, Yu (2005) suggested that astronomy education remains the main aim of planetariums just like it has always been across the historical timeline of this medium and although such relationship has always been questioned for the reason that astronomy concepts, regardless of their simplicity, are difficult for the public to understand, planetariums and educational material remain intact. Complexity of analogue systems that operated planetariums in the past were managed successfully, yet just like digitisation took over every other area in the media industry, Lantz (2002) investigates how projection workflows of planetariums shifted from analogue optomechanical based projection to digital projection since the beginning of the digital age of planetariums in 1982, and how such a shit changed the landscape of planetariums in terms of production, system requirements and the overall economics of the medium.

The notion of planetariums to the general public has always been linked to education, stars and astronomy. This stereotype about fulldomes often leads to doubting their growth. However, for a medium that has only been in existence for two decades in its digital form, Yu (2008) stated that fulldome theatres have seen growth in numbers. Growth of digital fulldomes is not theoretical and is demonstrated statistically by Neafus (2012) with the aid of charts that illustrate fulldome theatres exceeding the number of IMAX theatres worldwide. Growth of fulldomes is not limited to numerical statistics as stated by Yu (2008), the technicalities, workflows and overall culture of fulldome theatres is also in constant change as growth continues. Bourke (2007) stated that growth of this medium have increased the variety of content in fulldomes. Implying that fulldome content and applications are no longer exclusive to astronomy, as content in dome theatres now includes artistic visualizations, music and entertainment. Confusion in the fulldome community about whether a fulldome medium is an educational tool, a digital dome or a future cinema is an important consequence of this rapid growth of digital fulldome as explained by Bourke (2007).

Sweitzer (2005) described maintenance costs, costs of hiring qualified staff, and continuous innovation in new programs as some of the challenges currently facing digital fulldomes. Lantz (2007) highlighted large space requirements, optimization of image resolution and brightness and real time spherical mapping as some of the main technical challenges faced in the fulldome medium. Development of standards is marked as one of the biggest challenges facing the fulldome medium (Lantz, 2007). Bourke (2013) explained that duplicating production standards of the cinema industry would eliminate the creative and experimental aspects of the fulldome medium. Challenge of storytelling in fulldome shows is raised by Wyatt (2005) as he argued that immersive domes are yet to have as much time as established cinemas to develop a narrative language. Furthermore, the main aim of a fulldome remains to be taking the audience in a journey than watch a story (Wyatt, 2005).

Creating content for one fulldome will not necessarily work on all fulldomes due to the lack of standardization and the way each fulldome operates. Fulldome content creators face their own unique challenges. Bourke (2007) explained that creating fulldome content is not a skill that is taught in educational institutions in many

countries worldwide. Accordingly many, if not all, fulldome artists are not trained to contribute in this medium and are forced to be self-trained to create large format content. Technical challenges in immersive displays are the main reason behind the lack of interest of the research community in the fulldome medium (Lantz, 2007). Bourke (2007) highlighted high rendering requirements, constant need of render farms, lack of small preview options, difficulty of capturing live footage and the absence of dome formats editing tools in many of the present software as some of the key challenges faced by fulldome content creators. Despite all these challenges in fulldome content creation, Lantz (2011) suggested that the advancements in technology and 3D soft-ware will eventually help fulldome content artists to create unique content. Furthermore, Bruno (2008) demonstrated that making an investment of shows through licensing to multiple beneficiaries is an advantage that content creators did not have a in the past. However, Lantz (2011) stated that implementing the industrys standards for content creation and distribution order is still a necessity for fulldome content creation to flourish.

B) Methodology

Working closely with the Thinktank Science Museum (Thinktank, 2014) Digital Planetarium in Birmingham and contacting fulldomes around the world allowed an exploration of how fulldomes operate at present, how they could be utilised in the future and the current along with potential difficulties facing the medium.

Monitoring the growth of all fulldomes worldwide is challenging, and there are no valid resources that prove to cover the growth of every single fulldome on a global scale including statistics provided by representatives of the medium. Growth of fulldomes was monitored in this research by obtaining data directly from fulldomes worldwide. Results of an online questionnaire that was sent to all fulldome theatres worldwide were analysed. Covering 19 countries on a global scale served the purpose and scope of this project and the feedback of fulldome managers worldwide exceeded initial expectations. A list of the countries involved in this research is shown in Table 1.

Country	Number of Fulldomes	Name of Institution/s
United States	4	- Valdosa State University - City College of New York Planetarium - Brazosport Planetarium - Pretlow Planetarium (Old Dominion University)
United Kingdom	4	- Southend-on-Sea Borough Council (Central Museum) - Houston Museum of Natural Science at Sugar Land - Cosmic Dome (University of Aberdeen) - Blakemore Planetarium (Museum of the Southwest)
Germany	3	- Mueller Planetarium - Zeiss-Planetarium - University of Applied Sciences (Institute for Immersive Media)
France	2	- Planetarium of Marseilles - GAP 47 - Observatoire du Fumelois
Colombia	1	- Cartagena Planetarium
Australia	1	- Adelaide Planetarium
Canada	1	- Star Dome
India	1	- Leo Planetaria
Spain	1	- Planetari de Castell
Catalonia District	1	- Parc Astronmic Montsec
Portugal	1	- Centro de Astrofsica da Universidade do Porto
Russia	1	- Star Express Planetarium
South Africa	1	- Wits University Planetarium
Switzerland	1	- Planetarium Zurich
Romania	1	- Baia Mare Planetarium
Turkey	1	- Space Camp Turkey
Denmark	1	- The Steno Museum Planetarium
Total Number of Countries	**Total Number of Fulldomes/Institutes**	
19	**28**	

TABLE I: Countries and Institutes involved in the research

Challenges facing fulldome producers were investigated through direct contact with the inventor of the spherical mirror projection system. This approach provided succinct opinions about the challenges faced by fulldomes, causes of such challenges and whether these challenges

are valid or not. In addition, firsthand experience of developing fulldome content was accomplished solely to go through the same experience as any fulldome artist would go through in fulldome content creation. Going through the same development experience of creating fulldome content and facing the same challenges as any other fulldome artist allowed better judgment of the full- dome medium, its challenges and its current content creation workflows.

Potential future workflows of digital fulldomes was explored through direct contanct with the co-founder of IMERSA (Immersive Media Entertainment, Research, Sience and Arts), Ed Lantz. Analyzing the insights of the co-founding director of IMERSA added value to the conclusions drawn about fulldomes in this research, as IMERSA shapes the standards of this medium and how it is likely to operate in the future (IMERSA, 2013). Furthermore, direct contact with Don Carmody, Hollywood movie producer of the Resident Evil movies, provided a cinematic perspective about digital fulldomes. This approach added significant value to this research. To our knowledge, all previous literature around this subject lacks any contact with key representatives of similar industries that could benefit the fulldome medium.

Current Workflows of Fulldomes

Projection technologies

DLP (Digital Light Processor) projectors use micro images to project an image, or a video, on a digital fulldome. DLP projectors are known for their high brightness that goes up to 27,000 lumens (Lantz, 2005) in fulldome theatres. High brightness is a significant advantage in fulldome applications as it improves the immersive experience for the audience in a dome theatre for the reason that it makes it easier to follow shows projected on the dome. High costs remain a disadvantage as prices of DLP projectors.

LCoS (Liquid Crystal on Silicon) projectors market is relatively small in comparison with other projector technologies. However, it is expected that this market will grow as LCoS offer high resolution, brightness and saturation. Such features improve the projection of any fulldome show. The biggest advantage of LCoS projectors is that they eliminate any rainbow or screen door (Lantz 2005) effect that is present in other projector technologies. LCoS projectors share the same disadvantage as most projectors in the fulldome medium: high costs.

CRT (Cathode Ray Tube) projectors offer the highest contrast ratio in the fulldome medium. This advantage is important in educational applications and astronomy as high contrast means brighter and clearer stars to the audience. High resolution and better black areas than any other projector in the industry are also some of the advantages of CRT projectors.

Although CRT projectors are considered amongst the best in the industry and are still widely used, they are often criticized for their high maintenance costs, lack of portability, low brightness and high costs: factors shared with other projectors used in the fulldome medium.

High contrast ratio, brightness and saturation levels advantages introduced laser projection systems in 2002 to the fulldome medium (Bourke, 2012). Alongside high brightness and contrast ratio, laser projectors also offer and a long lifetime which reduces maintenance costs. Fulldome theatres tend to avoid utilizing laser projection systems due to the extremely high costs of these systems. Moreover, safety precautions regarding lasers, cooling requirements of laser based projectors and signal interference (both constructive and destructive) which adds

granular noise in images projected are other disadvantages of laser projectors. Recently developed grating light valve technology forms pixels of images in a silicon chip which then becomes the source of display projection on any screen regardless of its size. This development benefits the fulldome medium as it offers high resolution up to 8K x 8K (Lantz, 2005).

Projection methods

Single or dual projectors with a fisheye lens:

Using single or dual projection systems that are attached to a fisheye lens as shown in Fig. 1 is considered to be the simplest way to project fisheye images on a digital fulldome (Bourke, 2007). This projection method is widely used in small domes that offer content that does not exceed 2K in resolution as that is the highest resolution offered by a single or dual projection system. This projection system is effective in small applications in small domes; however, chromatic distortion at the rim of the dome and loss of light through the lens are some of the disadvantages of this system (Bourke, 2007).

(a) Single projector with fisheye lens (Bourke 2012).

b) Dual projectors with a partial fisheye lens (Bourke 2012)

Figure 1: Single and Dual projection methods

Multiple projectors:

Multiple projectors systems offer the highest resolution in the fulldome medium. Resolution of multiple projectors systems has been continuously increasing. 4K x 4K is the current resolution employed by most digital fulldomes; however 8K x 8K resolution is also currently available in some digital fulldomes. Multiple projectors (5 to 7 projectors) are spread on the rim of the dome; in consequence they do not affect the seating arrangement of the dome theatre and are usually not seen by the audience. Each 4K image is sliced equally depending on the number of the projectors as shown in Fig. 2. Each projector then presents a part of the 4K image on the dome; all the sliced parts of the images are blended together by the system installations.

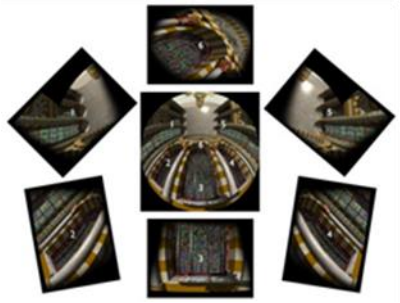


Fig. 2: Multiple projectors system. (Bourke, 2012)

Spherical mirror projection:

The invention of spherical mirror projection by Professor Paul Bourke shown in Fig. 3 significantly helped the fulldome medium, as many fulldomes worldwide in the present day utilize spherical image projection. Low maintenance costs and easy installation are also some of the major advantages of this system. This system employs a single projector and a spherical mirror that scatters light across the dome, Bourke (2012) stated that the resolution of this system could raise up to 1600 pixels if a good HD projector is utilized. Although

the usage of this system is growing on a global scale, it is often criticized for the difficulty to maintain a uniform focus across the dome, a feature that is directly related to the quality of the projector used. Moreover, resolution limitations could force this system to be out of reach for fulldomes that would want to utilize this system in large applications that exceed 2K resolution.

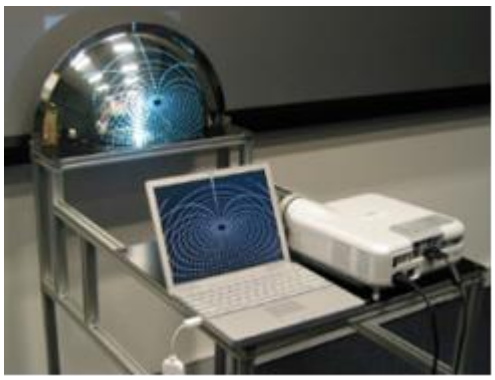


Fig. 3: Spherical Mirror projection. (Bourke, 2007)

Theatre design

Dome types

Inflatable domes: Portable domes are usually small in diameter and utilize a maximum of two projectors. Al- though the outer surface of these domes is usually made up of fabric that is partially visible which limits the immersive experience (Bourke, 2007) as shown in Fig. 4, education is generally the main application of portable domes, hence the educational material is more important than the immersive experience in this case.

Fig. 4: Portable domes (Bourke, 2007)

- Hard shell domes: Presently known as iDomes, are usually 6 meters in diameter as shown in Fig. 5 and are often used in gaming venues and trade shows (Bourke, 2007). iDomes experienced successful stereoscopic tests, these trials offer an improved experience to the user with the 3D element being present (Bourke, 2008).

Fig. 5: iDomes (Personal domes) (Bourke, 2008)

- Traditional planetarium dome: Planetarium domes have a solid structure that is built from steel. Traditional planetariums that only project stars and astronomy shows usually have one projector in the middle of the planetarium. The digital age of fulldomes introduced using multiple projectors that are scattered across the rim of the dome and not in the middle, or on the ground, of the dome theatre.

- Plane faced domes: Geometrical domes are the easiest domes to build and are usually built for their artistic appearance as shown in Fig. 6. The immersive experience in these domes is not as good as other domes as the surface of the dome is clearly visible to the audience (Bourke, 2007).

Fig. 6: Geometrical planetariums (Bourke, 2007)

Seating arrangements:

- Omnidirectional: Omnidirectional or concentric arrangement is the most common in traditional planetariums that have a purpose exclusively dedicated to showing stars and nights sky. Seats surround the singular analogue projector in the middle of the planetarium as shown in Fig. 7.

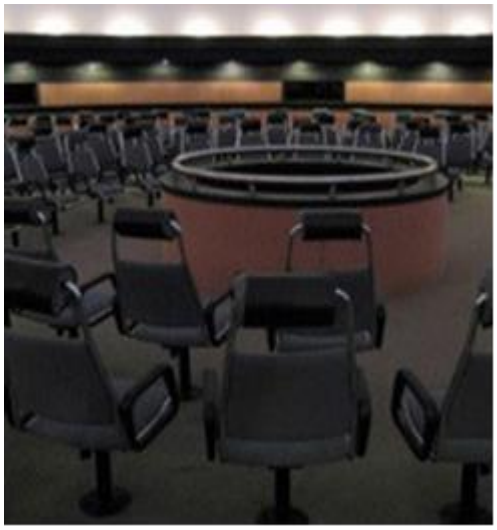


Fig.7 Omnidirectional seating arrangement (Bourke, 2012)

- Unidirectional arrangement: Unidirectional arrangement is the most common arrangement in the fulldome medium at present as most digital dome theatres are designed to project movie content. This seating arrangement turns the attention of the audience to a single point of focus that is called the sweet spot, the position of that spot is in the opposite direction of the eye level of the audience as shown in Fig. 8.

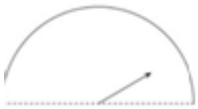
Dome orientation:

Fig. 8: Unidirectional seating arrangement (South Florida Museum, 2012)

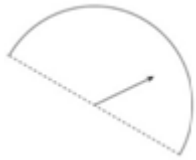
- 0 degrees orientation: Concentric and traditional planetariums usually have 0 degrees orientation, therefore the dome is not tilted and perfectly horizontal at the top of the audience as shown in Fig. 9(a).

- 30 or 45 degrees tilt: OmniMax theatres, or IMAX Dome as they are renamed now, commonly have tilted domes by 30 or 40 degrees as shown in Fig. 9(b). This tilt improves the immersive experience in a digital dome theatre as it gives the audience the feeling that they are inside the projected movie. Most digital dome theatres are currently tilted which shifts the sweet spot of action to a common place in most dome theatres (see Fig. 28).

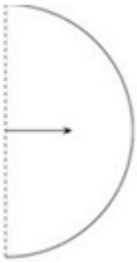
- 90 degrees tilt: iDomes or personal domes have a 90 degrees tilt for the reason that they are designed to be standing horizontally. 90 degrees tilt in iDomes face the audience or the users as shown in Fig. 9(c), thus the sweet spot of the action should be exactly in the middle of the iDome.



(a) 0 degrees tilt angle
in traditional planeta iums (Bourke, 2012)



(b) 30 or 40 degrees
tilt in OmniMax theatres (Bourke, 2012)



(c) 90 degrees tilt
in iDomes (Bourke, 2012)

Fig. 9: Dome tilt angles

Current applications

Planetariums in their digital form are still being utilized in education and astronomy. Digital fulldome theatres are con- stantly receiving funding from giant organizations like NASA (National Aeronautics and Space Administration) which en- courages development of educational shows in this medium. Visualising any database (McConville, 2005) in fields such as chemistry, astronomy and physics is also a big part of the current fulldome educational mission. Introducing iDomes allowed training and simulation in fields such as aviation and driving. Moreover, iDomes introduced a new adaptation of video gaming where gamers could interact with a personal digital dome instead of the normal TV screen. Commercial producers in the fulldome medium take advantage of a medium that attracts young age groups to promote their products in a form of a short show/advert. A good example of this is the Trojan condoms advert (Trojan Dome, 2014) that was distributed in planetariums worldwide to promote their product and send a message about safe sex to young people that visit digital dome theatres. Fulldome theatres currently contribute to promoting tourism in the countries or locations they are in by giving tourists a virtual, immersive experience in a specific area, as most digital dome theatres are a part of local museums and science centres. Some examples of this include Thinktank Planetarium being a part of the Thinktank science museum (Thinktank, 2014) in Birmingham, and Sir Patrick Moore Planetarium (Howell, 2014) being a part of the National Space Centre in Leicester. Technological advances introduced enter- tainment applications in the fulldome medium. Entertainment shows are not established or accepted in the fulldome medium as desired yet, this is due to the domination of educational and space related shows. However, many digital fulldomes have moved from the traditional projection of stars and night sky to experimental art and shows that have storylines which could help this application grows in the future. Real time applications recently broke into the fulldome medium, allowing various music acts to perform alongside fulldome visuals in real time. Real time application helps to give the audience an extra immersive experience alongside the music performance.

3) Growth of Fulldomes

Present trends show that digital fulldomes have experienced tremendous growth in the past decade in terms of audience, number of theatres, number of shows and fulldome producers.

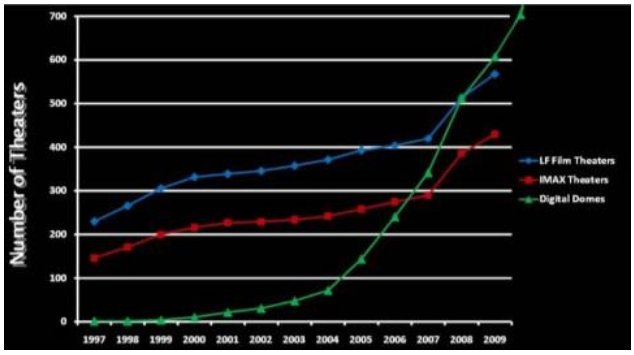


Fig. 10: Digital domes growth in comparison with other film formats. (Neafus, 2012)

Fig. 10 shows that the number of digital domes now outnumber the number of IMAX and film theatres. Low technology costs, high audience impact of fulldome technology and distribution standards are some of the factors that helped fuel the growth of fulldome technology as addressed by Bruno (2008). Although some of these factors did help fulldome technology to grow radically in the past decade, some of these factors still stand as barriers to even bigger growth of digital fulldomes. Technological costs are not necessarily low, as independent fulldome producers still complain about high production costs. However, distribution standards that only became available in the beginning of the digital age of the fulldome technology eased the financial pressure and showed major growth in the number of fulldome producers.

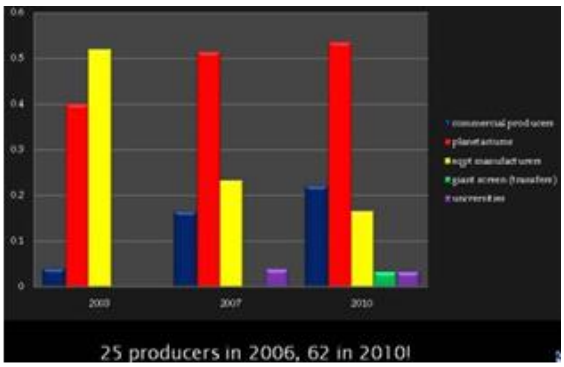


Fig. 11: Growth in the numbers of fulldome producers (Neafus, 2012).

Growth in numbers of fulldome producers in a time span of just 4 years as shown in Fig. 11 is impressive and proves that the fulldome medium is in continuous growth. Moreover, increasing numbers of commercial producers is also a boost to the distribution standards introduced to the fulldome medium. These statistics prove that these standards work and producers are making returns on investment. The impact of distribution standards is also reflected on the number of shows in the fulldome medium, as fulldome producers are driven by the chances of making profits out of their shows. This increases the amount of content projected on digital domes which eventually increases numbers of fulldomes visitors.

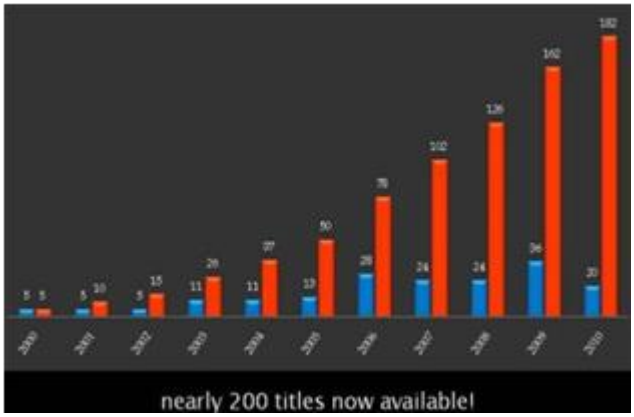


Fig. 12: Growth in the numbers of fulldome shows (Neafus, 2012).

Despite the genres of shows produced, an increase in the number of fulldome shows (182 different shows in 2010 as shown in Fig. 12) is always an advantage in terms of audience attraction as visitors of fulldome theatres are always interested in new shows. Growth of shows and fulldome producers eventually leads to growth in audience. This growth was monitored in this research as 19 different countries offered their own statistics about audience growth.

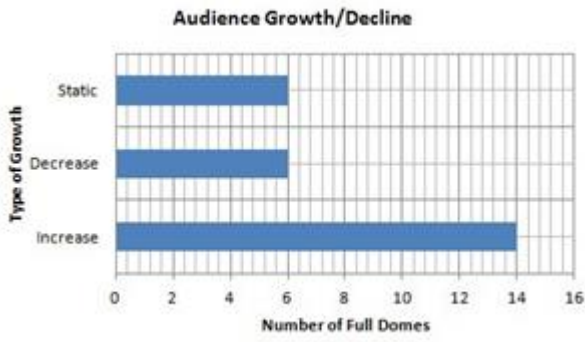


Fig. 13: Audience growth in fulldome theatres

As illustrated in Fig. 13, most of the digital fulldome theatres in different countries that participated in this research experienced growth in attendance in the past few years. This proves that the growth of the fulldome medium is not only limited to its production element, its growth has extended to reach higher numbers of audience as visitors of fulldome theatres increase on a global scale.

Challenges Facing Fulldomes

Many challenges face the fulldome medium on several fronts; this section will be divided into three categories to ease the analysis of these challenges: global challenges, content creation challenges and economic challenges. Realistic solutions to overcome these challenges will also be presented.

Global challenges

1) Standardization:
Even though this medium has been existent for over two decades in its digital form, the fulldome medium still lacks standards that unify all fulldome theatres. Many representatives of fulldome theatres worldwide that participated in this research suggested that the image format of dome content, called the dome master, is the only real standard currently present in the fulldome medium. Even though introducing dome masters as a specification eased the process of production and distribution of shows, the true identity of fulldomes remains obscure in the absence of standardization. Introducing specifications for dome theatres to unify the immersive experience in terms of image and audio quality is another area in standardization that needs to be addressed according to Lantz (2013). Unifying dome theatres would be an important step in the standardization process as fulldome produces will not need to be concerned about their shows not being projected as desired on different dome theatres. Bourke (2013) stated that the degree of standardization needed in the fulldome medium must be specified. Digital fulldome theatres are a new field that allows artists from all parts of the world to take part in it, thus the degree of standardization applied in this medium must be done carefully. Duplicating the standards of the cinema industry where the number of suppliers is limited and the theatres are told what to show could prove to be a mistake, for the reason that this approach would eliminate the experimental element of fulldomes and would make it extremely hard for artists with limited budgets to create any kind of content. However, duplicating the standards of the cinema industry in unifying image and audio quality across all fulldome theatres could help standardize the fulldome medium in a way that improves content production and not minimize it. Lack of standards in the fulldome medium causes a conflict in the purpose of digital dome theatres, as many believe digital domes are an educational tool and will never be more than that, whereas others believe the digital domes have much more to offer than typical astronomy education. Bourke (2013) explained that fulldome visitors are usually looking to be educated and not entertained. However, an immersive medium such as the digital fulldome, should be open to accept all forms of art and all genres of shows, just like watching different genres of movies in a movie theatre, yet there are many fulldome theatres representatives

that still believe fulldomes should remain a tool that is only related to astronomy. Standardizing the purpose and mission of digital fulldomes is significant for the fulldome medium as a whole. Having a clear purpose of what could and could not be done in fulldome theatres is an important guideline that should be known to the whole fulldome community. This will ease the minds of fulldome producers that are constantly worried about their show not getting projected on a certain dome theatre because it is against the mission of that specific digital fulldome. Technically, fulldomes will never be standardized until the same immersive experience is achieved in every single digital dome theatre on a global scale; however, many in the fulldome community believe that standardisation of the fulldome medium is not far off as all the efforts of IMERSA in this field are in advanced stages.

2) Audience:

Fulldome theatres attract many visitors annu- ally on a global scale. Age groups of fulldome visitors were investigated as part of this research. More than 19 countries presented the most visiting age group to their fulldome theatres.

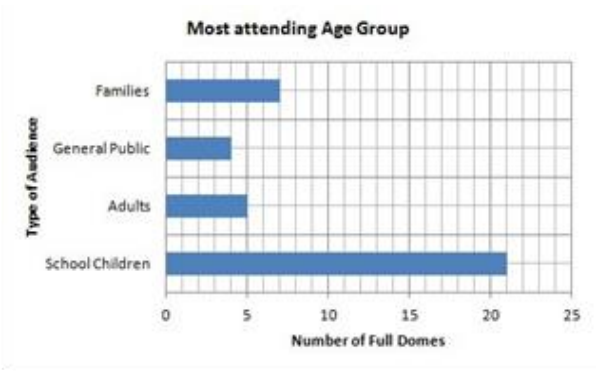


Fig. 14: Age groups in fulldome theatres

School children are the age group most frequently in full-dome theatres in 19 countries worldwide as shown in Fig. 14. Although this may not be a typical challenge to the fulldome medium, it forms a challenge that the most attending age group of fulldomes remain to be school children. These results show that the fulldome medium still finds it challenging to attract all age groups constantly; this is mainly caused by the lack of variety in fulldome shows. Astronomy education will always remain a vital part of school children's curricula, which explains the reasoning behind this age group being the dominant audience category in fulldomes. However, school children will at some point reach a certain age that draws them away from educational material to a more entertaining medium. This challenge is not presented to diminish the importance of education in anyway; however, all age groups (excluding school children) will not visit a fulldome theatre once every weekend for pure entertainment. Introducing more shows that are not educational or related to astronomy would attract more age groups to fulldome theatres as it would only then break the only educational stereotype about digital dome theatres.

3) Lack of variety in shows:

Digital fulldomes have always been labeled as an educational tool; this is reflected on almost all fulldome shows. Education is the main element in most of the shows projected on all digital domes worldwide. Exploring most and least viewed shows on different fulldome theatres worldwide was investigated in this research.

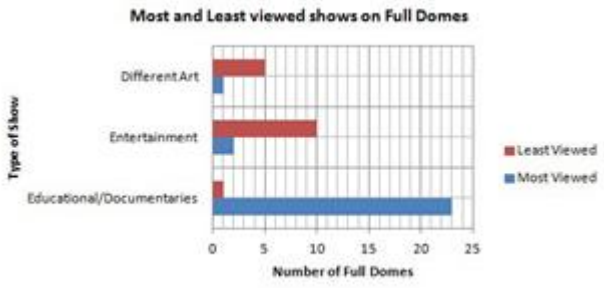


Fig. 15: Most and least viewed shows in fulldome

Educational shows are the dominating genre in the fulldome medium as illustrated in Fig. 15. On the other hand, entertainment and other artistic shows are the least viewed shows on a global scale. Bourke (2013) agreed that there is not a wide range of genres in the fulldome medium. This proves that the purpose of digital fulldomes still remains an educational one, and the acceptance of other forms of artistic and entertainment shows is yet to be accomplished. This problem does not only lure some age groups away from digital fulldomes, it also forces fulldome producers to step away from creating entertainment shows to avoid making a loss in the fulldome market. This is for the reason that many fulldome theatres would not project or license entertainment and artistic shows. Unifying the purpose of all digital fulldomes on a global scale mounts as the only solution to such a problem. This approach could tempt digital fulldomes to be more open about other genres of fulldome content that are outside the educational scope.

B) *Content creation challenges*

1) Production costs:
Many key thinkers in the fulldome community do not agree that production costs of fulldome shows are higher than any other medium. Bourke (2013) argued that producing a fulldome show is not necessarily harder than producing a flat screen production that has similar standards to the fulldome medium in terms of resolution and image quality. Bruno (2008) further illustrated that the digital age of the fulldome technology eased the production process and the financial pressure on fulldome artists, for the reason that funding projects is now available in the fulldome medium by local film boards or private equities cashed in by individual investors. Moreover, major organizations like NASA and the National Science Foundation also provide funding for fulldome projects. Even though applying for that kind of funding by large organizations is exceptionally competitive, expensive and time consuming, the fact that it exists is a dividend that was never existent in the fulldome medium a decade ago. Production costs of fulldome shows mainly depend on the financial power of the production company or investors and the magnitude of the project. Claims of representatives of the fulldome medium that production costs are now relatively low are justifiable due to the presence of funding and licensing of shows. The main argument that rises with these claims is whether independent fulldome producers stand any chance in a market that is now driven by making profit. The chances of creative individuals having big budgets are low and thus producing shows that could compete with big production companies becomes a challenge. However, dome theatres will gladly pay lower licensing fees for small budget shows; this could be the only consolation to individual producers or small production companies.

2) *Licensing costs:*
Licensing of shows gives fulldome producers the chance to compensate their production costs through profits. Existence of shows licensing is a huge motivation for fulldome producers and it guarantees the continuity of shows production in the fulldome medium. Licensing costs depend on the size of the dome theatre projecting the show. Large domes will be charged high licensing fees. On the other hand, small and portable domes will be charged low licensing fees. Introducing distribution standards in the fulldome medium assures fulldome producers that taking part in this medium will eventually pay off. However, dome theatres are the opposing party that pay these licensing fees, investigating what digital domes worldwide consider of licensing costs was part of research.

While these results do not represent every digital dome theatre in the world, they still represent 19 different countries worldwide.

The issue of high licensing costs dominated the results of the biggest challenge facing dome theatres as shown in Fig 16, and was addressed by many dome theatre representatives that believe high licensing costs limit their ability to constantly project new shows. It could argued that producers should not be blamed for this issue as charging licensing fees is an essential process to try and turn costs into profit. However, most dome theatres are nonprofit organizations and are usually a part of educational institutions; hence in this case even most of digital dome theatres do not acquire high budgets or funding to keep their shows up to date. Having the exact same shows in all fulldomes on a global scale is technically not feasible; nevertheless, introducing a special pricing scheme for digital dome theatres that are known to be nonprofit organizations could solve this problem in an attempt that would encourage digital dome theatres worldwide to have similar, and up to date, shows to a certain degree.

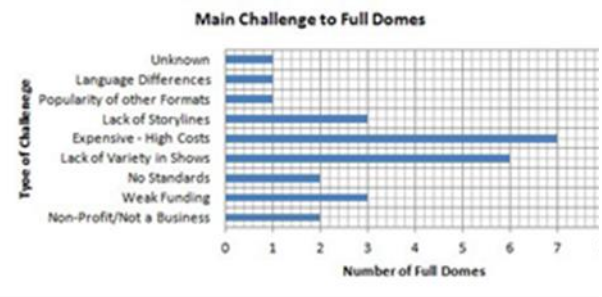


Fig. 16: Main challenge facing dome theatres

3) Storylines:
The missing storyline in the fulldome medium is a controversial problem that continues to be present, the fulldome community is divided into two opinions: one that suggests that there needs to be good storylines in fulldome shows to offer a better immersive experience, and the second suggests that the story element in its typical form is not a part of the immersive environment. Wyatt (2005) stated that an immersive theatre aims to shift the audience away from stories to a journey experience; the quality of that experience does not necessarily need a story that has a beginning and an ending. Lack of storylines limits the variety of shows as most of storylines are part of entertainment genres that do not necessarily have any educational material in them. Bruno (2008) advised fulldome producers to know their market when developing a show for the reason that educational and astronomy shows are currently dominating the fulldome medium. Bourke (2013) also clearly stated that visitors of dome theatres do not usually go to a planetarium to watch a thriller. Moreover, most of the successful shows that make profits and sell to dome theatres in the fulldome medium are purely educational. While the advanced level of graphics and visual effects in digital dome theatres are stunning, the lack of storylines and emotion lowers the attention span of the audience. Despite the fact that documentary narration is considered to be a part of immersive theatres, watching a show for over 30 minutes with the same narration in terms of emotion and sound levels will not maintain the same level of interest from the audience for the whole show. The fulldome medium must embrace other genres of shows that could offer better storytelling techniques, even though astronomy or education will always remain the leading purpose of digital dome theatres, introducing other genres of shows that could offer better stories would only increase show productions and more importantly, provide a better immersive experience.

Economic Challenges

1) Lack of funding:
Many digital fulldome theatres are non-profit organizations and are usually a part of an educational institute like a museum or a university. The economical nature of

dome theatres was explored in this research.

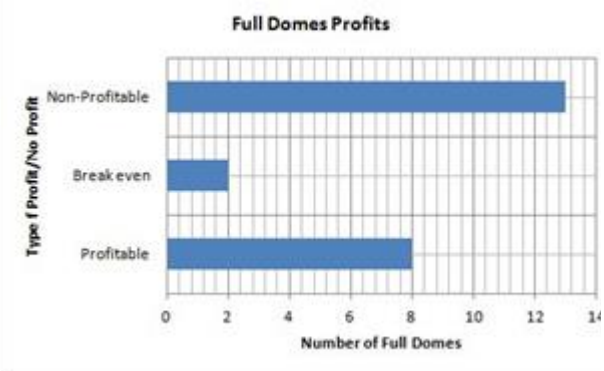


Fig. 17: Economical nature of dome theatres

Most of the dome theatres that participated in this research from 19 different countries were non profitable as illustrated in Fig. 17. Not having enough funding for digital domes affects the types of shows projected as they may be outdated. Furthermore, any upgrades in the software or the hardware of the theatre becomes extremely hard to implement when dome theatres operate as non-profitable organizations and are present just to educate the public. In addition, many dome theatres that are non-profitable are not able to innovate, fund any experimental content or host any fulldome festivals that could benefit these dome theatres. If standardization of dome theatres in terms of image and sound quality does happen in the future, many dome theatres on a global scale will not be able to follow those standards for the reason that they cannot afford it.

2) Monopoly behaviour of projector manufacturers:

Many personalities in the 2012 UKs FullDome Festival suggested that the major manufacturers of different projector technologies offer their products at an extremely high price, yet digital dome theatres are forced to buy these projectors for the fact that there are no other options to choose from. Types of upgrades in the past few years were investigated in this research to investigate to examine if this monopoly behaviour is affecting fulldome theatres.

The results shown in Fig. 18 suggest that even if there is monopoly behaviour from different projector manufacturers, investing in new projector technologies remains the main alteration in most dome theatres. This monopoly theory would be true if there were not any other projection technologies available. However, with the presence of more than one sup- plier of the technology and alternative projection techniques like the spherical mirror projection, which has proven to be favoured by many digital dome theatres, the competition in the fulldome medium seems to exist. Bourke (2013) clarified that projection technology manufacturers are not acting as a monopoly as there are at least 8 suppliers of projection technology in the fulldome medium, which is a sufficient competition in a growing medium and even more competition than in the movie/entertainment market where there is almost none. High expenses of digital projectors are not an issue that is exclusive to the fulldome medium; it is in fact how the digital projection market operates. Projector technology manufacturers could not be blamed for charging high prices for ground breaking innovations, the problem lies within the funding of digital dome theatres. These prices are not likely to change as innovations by big manufacturers will most likely get more advanced in the future which would only improve the fulldome medium and may even cost more.

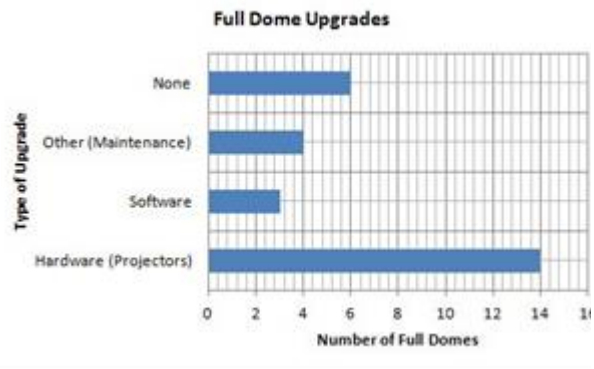


Fig. 18: Upgrades in dome theatres

First-hand content creation challenges

Fulldome content was created as a part of this research (shown in Fig. 19) to test current workflows of digital domes; many challenges were faced in the process of creating full- dome content. Some of the personal challenges faced will be discussed in this section.

1) First experience in the medium: the struggle with getting used to the fulldome medium and how it operates starts with the absence of this subject in almost all universities in a global scale. Creating fulldome content is not taught in any educational institutes, all the research around the fulldome medium and content creation must be done independently. Skills in different multimedia applications were existent, such as 3D modelling and animation. However, outputting the short movie in a form of dome masters required extensive research and testing on the dome to accomplish. Although there are many online resources, papers and slideshows by key thinkers in this field, the fulldome medium desperately needs published and documented books by key thinkers. This will encourage universities worldwide to consider including this medium in their courses.

2) Various options: different approaches in creating fulldome content are mainly caused by the availability of several animation tools. Although having several options to create content is an advantage that gives fulldome producers more options in choosing their own approaches to develop shows, choosing a tool that is not famous in the fulldome medium could backfire. Using Autodesk's Maya in this project required more research to choose all the right plug-ins and tools to output the movie in the best way possible on the dome. Seeking advice from both this university's staff and Thinktank planetarium team was ineffective as knowledge in utilizing this tool for fulldomes is non-existent in both parties. Guidelines about how to use all the possible animation tools must be published in a simple manner that would attract more artists to the medium.

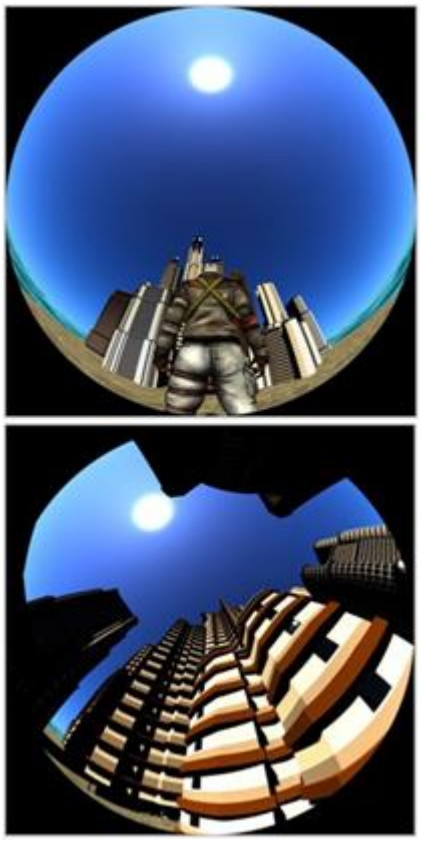


Fig. 19: Still images of the 3D movie developed

3) Post content creation: the movie created was a short story that falls into the entertainment category and has no educational element in it. This genre does not serve the mission of most digital

domes worldwide as it is not related to astronomy or education. Although the genre of the movie was chosen to be entertainment on purpose, the fact that this show was not shown to the public audience is disappointing. The longer it takes for the fulldome medium to accept other genres of shows, the more creative artists it pushes away from the medium that would certainly benefit from such diversity.

Potential Future Workflows of Fulldomes

Technological advances

Developments in cinematic cameras are a significant indication that future content on fulldomes could shift from prerendered 3D visuals to real life scenery that is shot with advanced cameras. The RED camera is the leading manufacturer of high resolution cameras that offer features that exceed the needs of the fulldome medium in its current shape. REDs latest products offer 1-100 frames per second at a resolution of 6K by 6K (RED, 2013). This development in cinematic cameras could prove to be beneficial for the fulldome medium if utilized efficiently in the future. It could be argued that the pricing of RED cameras is extremely expensive. However, investing in such cameras will be no different from investing in new projector technologies in terms of prices. The presence of these cameras in the fulldome medium could renovate the content projected in fulldomes in the future, as adding real life scenes to the shows in fulldomes, that are currently developed using only 3D animation techniques, would only make the immersive experience even more realistic for the audience.

Rendering powers and storage capacities are two of the biggest concerns to any fulldome producer, yet if there is anything to be learned from technological history it is that storage capacity will keep expanding. Processing powers of personal laptops and even render farms are in continuous growth. The relationship between hard drives and their capacity has been inversely proportional since 2001.

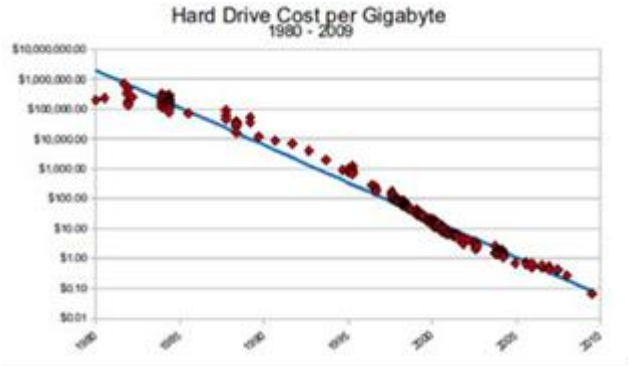


Fig. 20: Cost of hard drives per gigabyte. (Labourey, 2012)

Hard drive capacity has also been constantly increasing since 1980, and the prices of these hard drives keep dropping as shown in Fig. 20. These statistics indicate that the issue of high storage capacities will cease to exist in the near future in the fulldome medium. The same scenario is expected to happen in processing powers of computers, as rendering is a major challenge facing fulldome producers, processing powers are expected to get much more advanced in the future as illustrated in Fig. 21.

B) The future cinema

The fulldome community claims that digital fulldomes are the future cinema; however, a major Hollywood production did not yet occur in the fulldome medium. Bourke (2013) stated that a high production standard movie that uses the fulldome medium appropriately will be a significant milestone. Contacting a Hollywood movie producer was done in this research to get a cinematic perspective on digital fulldomes and whether fulldomes could become a medium that projects high production movies or not in the future.

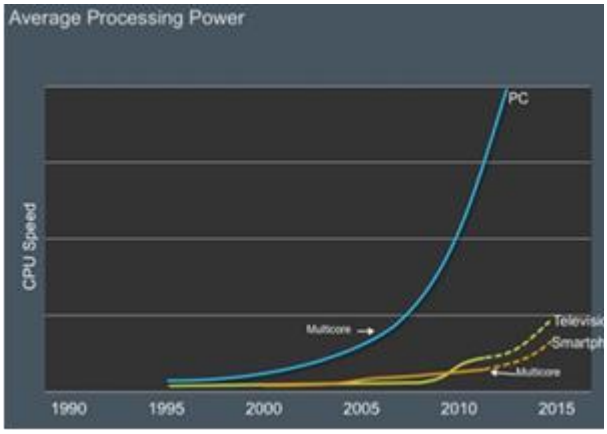


Fig. 21: Processing power expectations. (Frey, 2011)

Don Carmody, the movie producer of all the Resident Evil sequels, explained that IMAX theatres started out as digital fulldomes stand at present in terms of producing documentary shows that were projected in theme parks. The main audience for such shows were school children, the same audience that now dominates the fulldome medium. Devising a way to convert digitally shot films to the IMAX format was the starting point of attracting commercial films to be screened regularly in IMAX theatres. The timeline of the IMAX technology in the film industry is identical to the fulldome medium in the present day, and perhaps digital dome theatres should duplicate the experience of IMAX theatres by inventing a way that converts digital films into the fulldome format. However, fulldomes will not necessarily follow the same footsteps of the IMAX technology as many representatives of the fulldome medium believe that choosing shows instead of getting told what to show is an advantage that fulldomes have over IMAX theatres. This advantage allows the continuity of experimental applications on fulldomes, and more importantly, it keeps opportunities open for aspiring fulldome artists to take part in the medium, as they would not stand a chance in a very strict industry in terms of standardisation which is the case in IMAX theatres. Carmody (2013) also stated that the idea of filming a narrative film in a digital dome is not seem of interest to him personally unless the idea of the film forced itself towards the fulldome environment such as an adventure in outer space or underwater, as watching a standard drama in digital dome is more likely to annoy the audience than entertain them.

Although this is based on the opinion of only one movie producer, production companies in the cinema industry have their doubts about fulldomes becoming the future cinema, as the whole structure of digital domes does not seem to be suitable for big production movies. Claiming that digital fulldomes are the future cinema may sound premature to many in the fulldome community giving that the medium still does not easily accept genres of shows that are outside the educational scope. A big production movie in the current state of the medium will most likely be another, big budget, show about outer space.

Conclusion

Digital fulldome technology is still considered a risky and a new medium that is not yet fully explored. Even though the medium has been present for over two decades, the main mission of the technology is not yet clear to any observer. Based on the results of this research, it is evident that full- domes on a gloal scale are in constant growth; however, the fulldome medium still faces challenges, some of which are slowly getting resolved, while others remain to be in the same condition as they were at since the beginning of this digital technology. Even though distribution standards eased the process of shows production and licensing, competing with big production companies in the fulldome medium remains an obstacle to independent fulldome artists. Many fulldome theatres are trying to change the traditional mission of digital domes, yet it remains apparent that the fulldome medium in its digital form is still

dominated by educational shows and acceptance of other film genres and artistic approaches is not yet within the culture of the medium that has always been built on educational and astronomical standards. Digital fulldome theatres are existent in almost every country worldwide, and standardizing a medium on a global scale is a mission that is unlikely to happen, especially as the conflict about the purpose of digital domes remains unresolved, thus many digital domes are unlikely to follow standards or missions they do not believe in. The lack of standardisation in the fulldome medium keeps the innovation in digital domes vibrant, and duplicating the IMAX experience will only turn fulldomes into another technology that projects commercial shows. Technological developments will ease the process of content creation in the fulldome medium, though easing production of shows would not make a huge difference if other problems such as lack of variety of shows and missing storylines remain unresolved.

References

Bourke, P., (2013) Interview on Current and Future Workflows of Digital Fulldomes. Conducted by Kalbani, M. on 03/02/2013 via E-mail.

Bourke, P. (2007) Digital Fulldome - Techniques and Technologies. [shown at Perth: Graphite, ACM Siggraph] [viewed on 05/04/2013].

Bourke, P. (2008) Omni-Directional stereoscopy. [shown at Singapore: Siggraph-Asia user group meeting] [viewed on 11/04/2013].

Bourke, P. (2010) Digital fulldome for science research and public education. [shown at Kuching: Planetarium Sultan Iskandar] [viewed on 09/04/2013].

Bourke, P. (2012) Digital fulldome technology for content developers. [shown at Bangalore: Bangalore Association for Science Education] [viewed on 10/03/2013].

Bruno, M. (2008). Trends in Fulldome Production and Distribution; *Proceedings of the Fulldome Summit*, July 3rd, 2008, Chicago, pp. 1-11.

Frey, T. (2011) ”Invasion of the Digital Body Cloud”. Available at: http://www.futuristspeaker.com/2011/10/invasion-of-the-digital-body-cloud/ [accessed on 16/04/2013] .

IMERSA. (2013) ”Fulldome.ning Standards Forum”. Available at: http://www.imersa.org/standards [accessed on 17/04/2013].

Labourey, S. (2012). ”The Cloud as a Tectonic Shift in IT: The Industrialization of IT”. Available at: http://blog.cloudbees.com/2012/06/ cloud-as-tectonic-shift-in-it.html [accessed on 15/04/2013].

Lantz, E. (2002) The Digital Planetarium; in *Proceedings of the International Planetarium Society Conference*, Wichita, pp. 1-4.

Lantz, E. (2007) A Survey of Large-Scale Immersive Displays; in *Proceedings of the Emerging Display Technology Conference*, August, (2007): ACM SIGGRAPH. pp. 1-7.

Lantz, E. (2005) Immersive Cinema Basics. [shown at Espinho: Navegar Foundation] [viewed on 05/04/2013].

Lantz, E. (2011) Planetarium of the Future, *The Museum Journal*, 54(3), pp. 293-312.

McConville, D. (2005) The Discourse of Domes: Converging Approaches to Immersive Cinema Design. Part I: History, Applications, and Approaches. [shown at Espinho: Navegar Foundation] [viewed on 08/04/2013].

Neafus, D. (2012) Fulldome 101. [shown at Denver: IMERSA Summit 2012] [viewed on 08/04/2013].

RED. (2013) A Whole New Beast. Available at: http://www.red.com/products/epicdragon#overview [accessed on 09/04/2013]

South Florida Museum. (2012) Digital Full Dome Planetarium Theater. Available at http://www.southfloridamuseum.org/ThePlanetarium.aspx accessed on 15/04/2013].

Sweitzer, J. (2005) Feeding the Beast, and other Responsibilities of Digital All-Dome Planetarium Owners. *Planetarium: Journal of the International Planetarium Society*, 34(3), pp. 12-14.

Thinktank. (2014) "Last, First. (2014) Thinktank Birmingham science museum". Available at: http://www.thinktank.ac/ [accessed on 11/02/2014].

Trojan Dome. (2014) Trojan Dome. Available at: http://www.immersivedisplayinc.com/projects/case-studies/trojan-dome/ [accessed on 11/02/2014].

Wyatt, R. (2005) Planetarium Paradigm Shift, *Planetarium: Journal of the International Planetarium Society*, 34(3), pp. 15-19.

Yu, K. (2008) Future directions for research: Media aesthetics and fulldome Filmmaking; in *Proceedings of the Fulldome Summit*, July 3rd, 2008, Chicago, pp. 1-9.

Yu, K. (2005) Digital Full-Domes: The Future of Virtual Astronomy Education, *Planetarium: Journal of the International Planetarium Society*, 34(3), pp. 6-11.