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Abstract

In Computer Aided Design (CAD), technology is used as a means of drafting and generating representational drawings that adhere to architectural conventions. Although it can contribute to the digital carbon footprint, technology has propelled architecture to unprecedented heights because it provides advanced software, fosters architectural styles, aids in the development of smart cities, and promotes architectural restoration. This said, some critics believe technology in architecture is a hindrance as it obstructs the creative process, eliminates traditional methodology, and poses a threat to the health of the planet. However, I show that technology and traditional media should not be treated as separate entities; instead, they should be combined to achieve best results. This paper is important as it highlights the benefits that technology has offered architects and clarifies the false impression that critics have placed upon it. I conclude by providing solutions to maximize technology's potential and better equip future architects.

Keywords: CAD, parametric design, 3D modelling, contemporary architecture, smart cities

Technology in Architecture

In this paper, I argue that technology has propelled architecture to unprecedented heights. In this context, technology primarily refers to computer-aided design, which is the use of computers to perform design tasks such as 3D modeling and drafting (Shivegowda et al., 2022). Technology has undoubtedly become a prominent and integral part of people's daily lives and has provided an irreplaceable tool for architecture. Technology first entered the architectural realm with Ivan Sutherland's 'Sketchpad' and has since evolved to offer a broader variety of capabilities (Brown, 2009). However, concerns regarding the counter-effects of implementing technology in architecture still arise and limit its potential. Therefore, I address such issues and illustrate the advantages of integrating technology in architecture.

I support my position on technology in architecture with the following four arguments. First, I argue that technology equips architects with advanced software. This software facilitates working efficiency, which is attributed to the computer's ability to intake precise information, maintain consistent quality, and allow the designer ease of adjustment (Shivegowda et al., 2022). Second, I argue that technology fosters emerging architectural styles. As a result of the advanced technological capabilities, new architectural styles have emerged, most importantly 'Parametric Design,' exhibited by the works of Zaha Hadid (Bhooshan et al., 2017). Third, I argue that technology aids in the development of smart cities and sustainable living. This method of living can be achieved because technology today offers a means of managing public services, energy consumption, and building's tensile strength, in order to support the overall well-being of the community (Razmjoo et al., 2022). Finally, I argue that technology promotes a means of preserving architectural monuments. For instance, technology can be used for 3D modeling and printing to restore important monuments and embrace cultural identity (Acke et al., 2021).

I also consider three alternative views to my position. First, many people argue that technological intervention is a hindrance as it weakens the creative process (Torres et al.,

2015). Second, some may argue that technology in architecture causes an exclusive over-reliance and replaces the traditional free-hand drawing method (Brown, 2009). Third, others argue that technology should be limited because of its detrimental contribution to the digital carbon footprint (Kern et al., 2015). I show that while the above claims have merit, the bigger picture should be considered. For instance, free-hand drawing and computational design can exist simultaneously, providing the designer with a wider variety of tools (Claeys, 2022). This said, it is important not to neglect the greater capabilities of computational design.

This paper is important because of the surge of technological advancements in the 21st century. Architects should take advantage of the tools that have become readily available, rather than keeping a safe distance and holding onto what is familiar. Furthermore, keeping up with these developments is vital for designers so that such software and technologies may continue to expand to greater heights. Unfortunately, most current architecture curriculums do not accommodate these technological advancements, leaving students underprepared to enter the workforce where this software is used. Therefore, in accordance with the growing trajectory of technological advancements, future generation of architecture students should be equipped with appropriate digital skills (Hossain & Zaman, 2022). In order to achieve this digital integration into the curriculum, we must first acknowledge that technology has been a boon to architects.

Drawbacks of Technology in Architecture

Some people believe that technology in architecture poses more threats than benefits. For example, such people argue that technology obstructs the creative thinking process and impedes the designer. In addition, critics fear that an over-reliance on technology may well lead to the loss of traditional free-hand drawing methodology. Others also advocate for limiting technology's role in architecture because of its contribution to harmful carbon emissions.

Weakened Creative Process

Critics argue that technological intervention is a hindrance to the designer's creative process. More specifically, they believe that free-hand drawing is the driving force that kickstarts the creative thinking process (Torres et al., 2015). Traditionally, freehand drawing has been a fundamental visual tool that aids the designer with exploring and iterating their ideas. Drawings have evidently been the original precursor for many eminent architectural works. These works include Frank Gehry's Guggenheim Museum and Le Corbusier's Ronchamp Chapel (Nasr, 2014). According to Schütze et al., (2003) drawings have been a integral part of the creative process because of their role in facilitating problem-solving, active engagement from the designer, and continuous feedback from previous iterations to enhance the next ones. The authors also explain that drawing offers the designer a visualization of their ideas and aids in remembering these ideas.

Although free-hand drawing has traditionally been the fundamental tool, technology has since rapidly evolved. As a result, we have witnessed the emergence of a plethora of CAD software; however, it has not been without criticism. For instance, Brown (2009) argues that although it is capable of addressing non-theoretical issues, CAD cannot contribute to the problem-solving process as it does not accommodate the quick visual thinking nature of the design process. Thus, the author highlights the importance of following through the iterative freehand drawing process and finalizing the concept before venturing into the digital realm as it runs the risk of restricting the design's innovational potential. Guney (2015) found that introducing CAD in the studio can confine the designer's imagination. According to the author, the introduction of CAD has caused an unfavorable trend, witnessing the production of low-quality design disguised by exceptional visuals.

While the above claim has merit, the advantages of technology should be recognized. According to Nejadriahi and Arab (2017), implementing CAD in the studio boosts productivity because it allows the artist to input precise measurements and manipulate linear elements and geometries. Thus, the authors argue that architectural firms may not be able to function without the integration of technology. In addition, studies conducted at Al-Ahliyya

Amman University by Al-Matarneh and Fethi (2017) highlight a positive trend among architecture students opting for CAD.

Technology Replacing Free-Hand Drawing

Some may argue that implementing technology in architecture will replace traditional media. Brown (2009) fears the repercussions of CAD taking the place of the integral freehand drawing stage, causing an over-reliance on technology by the upcoming generation of designers. While this argument has some validity, it assumes that traditional and digital media cannot coexist. According to studies conducted at Al-Ahliyya Amman University by Al-Matarneh and Fethi (2017), 80% of students still use free-hand drawing in the conceptual stage only later switching to CAD. As such, the aim of integrating technology in architecture is not to completely eradicate traditional media from the creative process, but rather to acknowledge the advantages that technology offers.

In addition to the complementary nature of technology in design, Reffat (2007) highlights that software is now capable of aiding even in the problem-solving process. The author explains that such software provides ease of comparing various design choices and looking back at prior decisions to help the designer iterate and reflect, in turn facilitating the problem-solving process. Therefore, Nejadriahi and Arab (2017) posit that a mixture of primarily CAD and initial free-hand drawing is the key to generating successful designs.

Digital Carbon Footprint

Others argue that technology in architecture should be limited as it leaves a large carbon footprint. Patsavellas and Salonitis (2019) argue that digital manufacturing is responsible for high energy consumption because it requires storage and transmission of large amounts of data. In addition, Xing et al. (2016) explain that the Graphics Processing Unit (GPU) powering computers, which are necessary for running CAD, consume high amounts of energy because of the extent of resolution and detailed rendering required. Similarly, Kern et al. (2015) highlight that this power consumption is also heightened by high usage hours

and intensive software. Thus, the authors posit that ICT increases the emission of harmful gases and should reroute towards a more sustainable future first.

While the argument presents a reasonable claim, it should be viewed from a long-term position. Although technology usage consumes great amounts of energy, it also provides advantages that can help balance its negative effects. Horner et al. (2016) argue that the implementation of technology in architecture aids in the development of smart cities, which can ultimately lead to lower green house gas emission. The authors also discuss how technology has made collaboration digital, thereby reducing the amount of fuel used for commuting. Thus, technology's relationship with the environment can be difficult to manage; however, with all the advantages that technology offers, it should not be neglected.

Benefits of Technology in Architecture

Overall, the benefits offered by the implementation of technology in architecture outweigh its drawbacks. For example, technology offers a wide array of innovative software, equipping the architect with advanced capabilities. Additionally, technology fosters the emergence of ingenious architectural styles like the 'Parametric Design.' The use of technology in architecture has also facilitated the development of environmentally conscious, 'smart cities.' Finally, employing technology in architecture provides opportunities for restoring artefacts and preserving cultures' rich histories.

Advanced Software

The integration of CAD software in technology has increased working efficiency. Early CAD software could be traced back to 1963, by the original precursor, 'Sketchpad,' which implemented light pen technology and was later replaced by the prominent software, 'AutoCAD' (Malik et al. 2014). Later, a series of digital fabrication tools emerged, including SketchUp, Rhino, Grasshopper, and V-Ray, all of which cater to the architect's specific needs. As such, the myriad of software available provides ease of idea iteration, collaboration, and correcting errors. These technological drafting capabilities subsequently

boost productivity and save effort and resources because of the unmatched precision (Nejadriahi & Arab, 2017).

Alongside the representational tools, technology has also provided artificial intelligence (AI). AI has been introduced into the architectural field in many forms, including 'Generative Adversarial Networks,' which generate a variety of floor plan arrangements, and 'Machine Learning,' which is capable of understanding specific stylistic characteristics and implementing them in the output (Von Richthofen, 2020). Furthermore, Bashabsheh et al. (2019) show how virtual reality can enrich the architectural education and workplace. The authors explain that 4D visualizations offer the architect a more immersive look into the experiential aspect of the design. These visualizations are useful for ensuring a successful spatial procession.

In addition to CAD, technology has also aided in building construction. More specifically, the introduction of Building Information Modeling (BIM), which Hossain and Zaman (2022) explain is a system that combines information regarding the building's design, engineering, and construction into one system to achieve a more collaborative project progression. The authors highlight BIM's advanced capabilities in facilitating the design transition from a 2D drawing to a 3D model, including estimated costs and the use of actual materials. Additionally, the influential architect, Frank Gehry, who famously pioneered 3D technology in his design, introduced the aerospace CAD software, CATIA, into the architectural realm (Baxter & Berente, 2010). The use of CATIA can be exhibited through the production of his world-renowned 'Guggenheim Museum' in Bilbao.

Emerging Architectural Styles

Technology can also enhance architecture stylistically. More specifically, rather than simply using technology as a representational tool, some architects such as the pioneering Frank Gehry, began to leap into the 3D realm before construction (Boland et al., 2007). Samdanis and Lee (2017) explain that this leap has enabled architects to think beyond flat plans, enabling them to achieve a greater level of complexity and geometries. As a result, the

‘Non-Euclidean’ architecture, identifiable by its curves and uninform geometries, was augmented. Through the use of CATIA, organization with contractors was achieved, and architecture began to witness what was previously deemed ‘impossible’ brought to life (Yoo et al., 2006).

Another prominent architectural style that is a product of technological advancements is ‘Parametric Design.’ Parametric design employs algorithmic computation to manipulate geometries and dimensions of a structure in a systemic manner (Ostrowska-Wawryniuk et al., 2022). This style is primarily exhibited by the works of Zaha Hadid and her colleague Patrik Schumacher. Schumacher (2004) explains how Hadid used to hand-draw exploded axonometric drawings and digitally translate them, while maintaining recognizable fluidity. Schumacher highlights the implications of Hadid’s methods, yielding a nuanced understanding of space, with less rigidity and definition. Such dynamism was achieved because of technological intervention.

Smart Cities

Technology has also aided in the implementation of ‘smart cities.’ A smart city, as defined by Alshuwaikhat et al., (2022) is one that is sustainable and conservative with its resources, and in turn actively protecting the environment and its citizens’ quality of life. The authors explain that tackling a large-scale issue, such as the one that cities are currently facing, requires a technological approach in order to compile and keep track of the extensive amount of data involved. The authors highlight the role of ‘urban computing’ in mitigating the effects of urbanization, such as using sensors to understand traffic patterns and develop a more sufficient urban plan. This technology can be incorporated into various city sectors, in order to unify efforts toward a smarter city.

While it can provide solutions on a macro scale, technology can also operate on a smaller scale. For example, Ye et al. (2021) discuss the function of the ‘building control system’ in managing equipment, energy consumption, and air quality. According to the authors, the system is equipped with sensors monitoring humidity, temperature, and even the

concentration of dust. The authors explain that the monitor can also detect the concentration of gas, to ensure the occupant's safety and sound an alarm if there is danger. Evidently, the implementation of building control systems in smart cities is not only a practical solution, but also works towards ensuring the user's comfort and convenience.

As a result of the technological advancements, many cities have started to work towards the smart city initiative. For instance, Kim (2022) discusses how India is currently redeveloping its towns using smart initiatives, to better manage its water and energy resources. Furthermore, the author highlights Japan's efforts to implement 'smart grids,' which are capable of monitoring power usage, to mitigate consumption levels. Dubai has also been an active contributor in this initiative, as it begins to implement smart roads, 'green buildings,' and electric cars (Razmjoo et al., 2022). As such, technology has helped the smart city initiative grow, as we collectively begin to become more conscious of the consequences of our actions on the planet.

Preservation of Architectural Monuments

Technology can also aid in the restoration of architectural monuments. Architectural monuments hold immense value in shaping a culture's identity, so preserving these artefacts for future generations is vital. According to Zhang et al. (2015), this restoration can be achieved through Additive Manufacturing (AM), which is the use of 3D printing to replace missing pieces of an artefact. The authors explain that this technology produces a more precise result, in comparison to traditional methods, because of the use of reverse engineering (RE) to analyze defects and ensure a more accurate restoration. Virtual technology can also be used in the reconstruction process as a means of further validating the accuracy of the restoration (Acke et al., 2021).

As a result of the available technology, many artefacts have been successfully restored. For instance, since much of Syria's rich history has been destroyed, initiative has been taken to restore its missing pieces. That is, 3D printing technology was used to replicate Palmyra's arch, which was destroyed during conflict (Martel, 2017). Additionally, Blitz

(2019) discusses how mosaics from Apamea, which have been lost to excavation, are now being restored virtually and physically. The author explains how information was retrieved through photographic archiving, and the original geometric patterns were digitally reproduced and printed.

Conclusion

In this paper, I argued that technology has propelled architecture to unprecedented heights. Technology has played an important role in the 21st century and has also lent a major helping hand to architects, one which will soon be considered irreplaceable for its many benefits. First, I highlighted the variety of complex software that has been developed because of technological advancements. Such software has redefined architects' capabilities and broadened their horizon of possibilities. Second, I demonstrated the emergence of architectural styles as a by-product of technology entering the architectural field. Architecture has witnessed an upsurge of design ingenuity, pushing forward the involvement of technology in architectural styles. Third, I argued that the inauguration of smart cities can be facilitated by the integration of technology into urban design. There has been ever-increasing concern over implementing smart cities for the sake of our planet, and technology has been deemed a suitable solution. Lastly, I explained that architectural monuments can be reinstated using technological aid. The restoration of heritage is integral to maintaining cultural identity and should not be neglected.

With the rise of technological integration in architecture, technology has also received considerable criticism. First, critics have posited that technology plays a destructive role in the creative process. Such critics have opposed the implementation of technology and doubted its relevance over the traditional free-hand drawing methodology. However, technology's incomparable precision has boosted productivity and in turn has become the backbone of most architectural firms. Second, many have argued that technology has overtaken the role of free-hand drawing. Free-hand drawings have historically been deemed the unrivalled architectural tool, and now the pencil is presumably being replaced by

computers. However, the co-existence of traditional and digital media should not be disregarded as it provides the key to successful design. Lastly, others argued that technology entering the architectural realm contributes to the carbon footprint. These people believe technology should proceed with limitations as its administration can be problematic. However, the benefits of integrating technology in architecture and urban design can also be optimized in order to counteract its harm.

This paper is important as it validates technology as an integral component of the architectural process in our day and age. Critics have misplaced negative light onto technology's implementation in architecture, neglecting the myriad of capabilities it has offered architects. The speculative fear of technology has stigmatized and tainted the progressive growth of technology in architecture. Ultimately, it is the acknowledgement of technology's unrivalled assistance to architecture that will enable us to fully capitalize on its capabilities. Therefore, the first step to further taking advantage of technology's maximum potential is to begin implementing computational design in architectural curriculums, and not merely as a representational tool. The lack of recognition of technology in education leaves students having to pick up important skills on their own, and not being equipped with the required digital expertise to enter the workforce. However, properly equipping students with digital expertise may enhance the field of architecture and CAD software. After all, technology is the future, and detaching it from architecture will only shut the door to the possibilities of reimagined spaces that enhance our dwelling experiences.

References

Acke, L., De Vis, K., Verwulgen, S., & Verlinden, J. (2021). Survey and literature study to provide insights on the application of 3D technologies in objects conservation and restoration. *Journal of Cultural Heritage*, *49*, 272–288. https://doi.org/10.1016/j.culher.2020.12.003

Al-Matarneh, R., & Fethi, I. (2017). Assessing the impact of caad design tool on architectural design education. *Malaysian Online Journal of Educational Technology*, *5*(1), 1–20. https://files.eric.ed.gov/fulltext/EJ1125128.pdf

Alshuwaikhat, H., Aina, Y., & Binsaedan, L. (2022). Analysis of the implementation of urban computing in smart cities: A framework for the transformation of Saudi cities. *Heliyon*, *8*(10), 1–10. https://doi.org/10.1016/j.heliyon.2022.e11138

Bashabsheh, A., Alzoubi, H., & Ali, M. (2019). The application of virtual reality technology in architectural pedagogy for building constructions. *Alexandria Engineering Journal*, *58*(2), 713–723. https://doi.org/10.1016/j.aej.2019.06.002

Baxter, R., & Berente, N. (2010). The process of embedding new information technology artifacts into innovative design practices. *Information and Organization*, *20*(3), 133–155. https://doi.org/10.1016/j.infoandorg.2010.04.001

Bhooshan, S. (2017). Parametric design thinking: A case-study of practice-embedded architectural research. *Design Studies*, *52*, 115–143. https://doi.org/10.1016/j.destud.2017.05.003

Blitz, A. (2019). Stepping stones: Virtual restoration and 3D visualisation of the tessellated 4th century Byzantine synagogue floor at Apamea on Orontes, Syria. *Digital Applications in Archaeology and Cultural Heritage*, *15*, 1–13. https://doi.org/10.1016/j.daach.2019.e00108

Boland, R., Lyytinen, K., & Yoo, Y. (2007). Wakes of innovation in project networks: The case of digital 3-D representations in architecture, engineering, and construction. *Organization Science*, *18*(4), 631–647. https://doi.org/10.1287/orsc.1070.0304

Brown, P. (2009). CAD: Do computers aid the design process after all? *Intersect*, *2*(1), 52–66. https://ojs.stanford.edu/ojs/index.php/intersect/article/view/117

Claeys, D. (2022). Physiological and cognitive discontinuities: From mythical mediation to implicit discretization of architectural design tools. *Frontiers of Architectural Research*, *11*, 1–14. https://doi.org/10.1016/j.foar.2022.06.008

Erdine, E., & Kallegias, A. (2017). Interwoven reinforced concrete structures: Integration of design and fabrication drivers through parametric design processes. *Design Studies*, *52*, 198–220. https://doi.org/10.1016/j.destud.2017.06.002

Guney, D. (2015). The importance of computer-aided courses in architectural education. *Procedia - Social and Behavioral Sciences*, *176*, 757–765. https://doi.org/10.1016/j.sbspro.2015.01.537

Horner, N., Shehabi, A., & Azevado, I. (2016). Known unknowns: Indirect energy effects of information and communication technology. *Environmental Research Letters*, *11*(10), 1–20. https://doi.org/10.1088/1748-9326/11/10/103001

Hossain, S., & Zaman, K. (2022). Introducing BIM in outcome based curriculum in undergraduate program of architecture : Based on students perception and lecture-lab combination. *Social Sciences & Humanities Open*, *6*(1), 1–11. https://doi.org/10.1016/j.ssaho.2022.100301

Jabi, W., Soe, S., Theobald, P., Aish, R., & Lannon, S. (2017). Enhancing parametric design through non-manifold topology. *Design Studies*, *52*, 96–114. https://doi.org/10.1016/j.destud.2017.04.003

Kern, E., Dick, M., Naumann, S., & Hiller, T. (2015). Impacts of software and its engineering on the carbon footprint of ICT. *Environmental Impact Assessment Review*, *52*, 53–61. https://doi.org/10.1016/j.eiar.2014.07.003

Kim, J. (2022). Smart city trends: A focus on 5 countries and 15 companies. *Cities*, *123*, 1–19. https://doi.org/10.1016/j.cities.2021.103551

Malik, S., Kumar, V., & Gahlot, P. (2021). An analogy between conventional and unorthodox CAD methods. *Materials Today: Proceedings*, *43*(2), 2098–2104. https://doi.org/10.1016/j.matpr.2020.11.889

Martel, A. (2017). *3D technology in the restoration of history*. 3Dnatives. https://www.3dnatives.com/en/3d-technology-restoring-history-191020174/#!

Nasr, E. (2014). The impact of digital architecture on freehand sketches through design process. *Emirates Journal for Engineering Research*, *19*(1), 49–60. https://eng.uaeu.ac.ae/en/research/journal/issues/v19/pdf_iss1_19/5.pdf

Nejadriahi, H., & Arab, K. (2017). A study on the impacts of computer aided design on the architectural design process. *International Scholarly and Scientific Research & Innovation*, *11*(8), 1054–1058. http://scholar.waset.org/1307-6892/10007636

Ostrowska-Wawryniuk, K., Strzała, M., & Słyk, J. (2022). Form follows parameter: Algorithmic-thinking-oriented course for early-stage architectural education. *Nexus Network Journal*, *24*, 503–522. https://doi.org/10.1007/s00004-022-00603-1

Patsavellas, J., & Salonitis, K. (2018). The carbon footprint of manufacturing digitalization: Critical literature review and future research agenda. *Procedia CIRP*, *81*, 1354–1359. https://doi.org/10.1016/j.procir.2019.04.026

Pershina, R., Soppe, B., & Thune, T. M. (2019). Bridging analog and digital expertise: Cross-domain collaboration and boundary-spanning tools in the creation of digital innovation. *Research Policy*, *48*(9), 1–13. https://doi.org/10.1016/j.respol.2019.103819

Razmjoo, A., Gandomi, A. H., Pazhoohesh, M., Mirjalili, S., & Rezaei, M. (2022). The key role of clean energy and technology in smart cities development. *Energy Strategy Reviews*, *44*, 1–8. https://doi.org/10.1016/j.esr.2022.100943

Reffat, R. (2007). Revitalizing architectural design studio teaching using ICT: Reflections on practical implementations. *International Journal of Education and Development*

Using Information and Communication Technology, *3*(1), 39–53. http://ijedict.dec.uwi.edu/include/getdoc.php?id=2196&article=276&mode=pdf

Samdanis, M., & Lee, S. (2017). White space and digital remediation of design practice in architecture: A case study of Frank O. Gehry. *Information and Organization*, *27*(2), 73–86. https://doi.org/10.1016/j.infoandorg.2017.02.001

Schumacher, P. (2004). *Digital Hadid*. Birkhäuser.

Schütze, M., Sachse, P., & Römer, A. (2003). Support value of sketching in the design process. *Research in Engineering Design*, *14*, 89–97. https://doi.org/10.1007/s00163-002-0028-7

Shivegowda, M. D., Boonyasopon, P., Rangappa, S. M., & Siengchin, S. (2022). A review on computer-aided design and manufacturing processes in design and architecture. *Archives of Computational Methods in Engineering*, *29*, 3973–3980. https://doi.org/10.1007/s11831-022-09723-w

Torres, A., Serra, J., Llopis, J., García, Á., & Cabodevilla, N. (2015). The need and experience of drawing with ingeniuty. An analysis of the graphic practice in architectural education. *Procedia - Social and Behavioral Sciences*, *191*, 2505–2514. https://doi.org/10.1016/j.sbspro.2015.04.626

Von Richthofen, A. (2020). Aurel von Richthofen, on tools, technology and society around the future of AI and architecture. *Architectural Research Quarterly*, *24*(4), 379–381. https://doi.org/10.1017/S1359135521000075

Xing, L., Li, T., Huang, H., Zhang, Q., & Han, J. (2016). Efficient modeling and analysis of energy consumption for 3D graphics rendering. *Integration*, *55*, 455–464. https://doi.org/10.1016/j.vlsi.2016.02.009

Ye, Y., Wang, Q., & Wang, J. (2021). Green city air monitoring and architectural digital art design based on IoT embedded system. *Environmental Technology & Innovation*, *23*, 1–14. https://doi.org/10.1016/j.eti.2021.101717

Yoo, Y., Boland, R., & Lyytinen, K. (2006). From organization design to organization designing. *Organization Science, 17*(2), 215–229. https://doi.org/10.1287/orsc.1050.0168

Zhang, F., Campbell, R., & Graham, I. (2015). Application of additive manufacturing to the digital restoration of archaeological artifacts. *Procedia Technology*, *20*, 249–257. https://doi.org/10.1016/j.protcy.2015.07.040