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How Additive Manufacturing Can Move from Art and Aesthetics to a Functional and Practical Role in Mainstream Architecture

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Abstract

This paper discusses how Additive Manufacturing (AM), better known as 3D printing, will go from just a technical demonstration within the construction industry to an actual functional and practical tool in mainstream architecture. The focus will be on Contour Crafting, a special form of 3D concrete printing. Contour Crafting automates construction of complex and customized architectures, thereby turning 3D printing from a novelty to a practical solution for construction challenges. The paper discusses 3D printing within the construction industry in general, the origin and the processes of Contour Crafting and what its benefits and downsides are over more traditional methods. While still a developing technology, Contour Crafting could become the mainstream method of construction, having the balance between efficiency and innovative design possibilities in architecture.

Keywords: Additive Manufacturing; Archtiecture; Construction, Contour Crafting

1. Introduction

Additive Manufacturing will change the way the construction sides of today look. It allows for design possibilities and construction methods that were not possible before. It could be changing the way buildings and construction sides look in the future since, once fully developed, building structures would be much easier to build, not only functional but also beautiful ones. Beyond the artistic uses, 3D printing would solve problems such as cost reduction, hastening of construction, and giving freedom for more creative designs.

3D printing in mainstream construction is being recognized for the many benefits it has. Among them, it will make building cheaper and faster, generating less waste, while allowing architects to explore more complex designs [1], [2]. It further allows the printing of whole sections of buildings with complex shapes, further opening possibilities in architecture [3], [4].

This paper addresses how additive manufacturing changes architecture, ways in which current methods and materials are leading, new technologies, benefits, and challenges brought by the changes. The main question this paper tries to answer is: How can 3D printing get from an art form into actual practical contribution to everyday building?

The paper will review the main methods of 3D printing used in architecture, discuss further developments, and determine which materials are used in construction. It will also address how 3D printing affects design possibilities, what makes it appealing to stakeholders, and ways in which 3D printing can be used in building projects.

2. Additive manufacturing in architecture

2.1. Methods of additive manufacturing

Additive manufacturing is becoming popular in architect design and building. This technology makes it possible to produce complicated structures by adding layer after layer of material. A few additive manufacturing methods are currently in the lead for architecture, each has its application and advantage.

Such a process is Fused Deposition Modelling (FDM). It finds application in architecture through designing a model that portrays detailed design and manufacturing components for non-load-bearing elements such as facades. This involves the melting of thermoplastic material, after which it is extruded through a nozzle with to make layers. It is an ideal technique for prototyping building elements and when material cost and accessibility are highly considered. For instance, FDM can create a model of building designs in detail, which can be used by architects to visualize the shape and complex geometries involved before full-scale construction.

Another technique of AM is represented by the layer-wise binding of powders through using a liquid binder. This technique is usable to create strong, large-scale structural parts like decorative facades or complex wall sections in architecture. Binder jetting may be used in creating feature walls in innovative architectural projects where there is a need for strength and customization.

SLA uses a laser to polymerize resins into solid layers. This method is ideal for applications requiring fine surface finishes and detailed prototypes, considering how accurate the methods for developing designs may be in delivering smooth surfaces. While it's widely utilized in making detailed architectural models, this method is ideal in applications requiring fine surface finishes and detailed prototypes.

One of the most well-known AM methods in construction is contour crafting. This is mainly used in large-scale construction projects. This technique involves casting concrete in layers to build structures directly from digital models. Such an approach is used for rapid construction of load-bearing walls and even whole building shells at a reduced time and cost. In relation to residential building construction, especially in the development of affordable housing and shelters in emergencies, the Contour Crafting technique would be suitable considering its speed and efficiency.

2.2. Architecture examples of applications

Additive manufacturing is being used in many kinds of applications in architecture. For example, fabricating highly detailed architectural models with FDM technology allows architects to have physical objects of their designs [4].

SLA has also allowed for the creation of precise, intricate pieces with little to no post-processing, such as specially designed interior design features that allow a designer to add unique features into their work with ease. Contour crafting has been used in the building of entire homes, showing how this technology can be beneficial in the speedy construction of green and low-income housing within a metropolitan area.

2.3. Effectiveness evaluation for architectural purposes

Additive manufacturing in architecture is efficient because it can produce complicated, custom-made designs at relatively lower costs and faster than any traditional method of construction. It offers great design flexibility, it allows architects to explore non-conventional forms and structures, providing efficient usage of materials-something that is totally in sync with modern sustainable building practice.

Furthermore, such AM technologies as concrete printing for structural components align with the end goals of the industry, such as reduction of construction times and customization of designs and functions to architectural needs [4]. It is this shift toward more automated, more precise, and greener methodology that better justifies greater inclusions of 3D printing into the construction industry.

Some applications were mentioned earlier, but there are three main types of additive manufacturing processes used in architecture and construction, these are D-shape, contour crafting and concrete printing [5]. The applications all share the principal to build structures layer by layer, but the techniques also have differences. The D-shape technique is typically used offsite, layering granular materials with a binder to create self-supporting structures without water curing. This process uses a hydraulic system to control binder and material deposition, and it is best suited for prefabricated elements. Moving to concrete printing, extrudes fiber-reinforced cement mortar, providing precise control for complex geometries. While effective for detailed designs, it requires additional support structures for overhangs and intricate shapes, making maintenance and quality control more intensive. And finally contour crafting, this stands out for large-scale on-site construction, employing trowels for smooth free-form surfaces. Its ability to autonomously build entire structures with minimal external support makes it particularly suitable for remote applications, a feature not possible with D-Shape or Concrete Printing.

2.4. Topology optimization

Topology optimization is a technique that makes 3D models more efficient by optimally distributing the material and using it only where it is needed. By means of a certain input and algorithms, the best design is found [6].

Topology optimization is becoming increasingly popular in the construction sector, where it is currently mainly used only in the first design phases. It is mainly used for creative purposes by architects, more as a tool for brainstorming, but it is not often applied in practice. One reason for this is that it often does not meet the design requirements of architects. In addition, the often-organic shapes that result from a topology optimization are difficult to realize in practice with traditional production techniques such as milling or casting [7].

Due to the rise of Additive Manufacturing, topology optimization can be more than a tool that can be used by architects only for brainstorming, because AM allows the designs to be realized easier. This can have many advantages. For example, by optimizing a bridge, the material can be adjusted to meet the weight requirements that will be placed on it. This saves on the weight and material of the bridge itself, the construction time and construction waste, which ultimately reduces the overall construction costs.

2.5. Multi material additive manufacturing

Multi-material additive manufacturing (MMAM) is an emerging technology in construction and architecture that integrates multiple materials within a single printing process, reducing the need for separate assemblies [7]. While AM with single materials has been studied for over a decade, multi-material applications in architecture remain relatively new. To expand MMAM's potential beyond load bearing uses, further advancements in suitable materials and properties are essential. Among various AM techniques, material extrusion is currently the main focus for large-scale 3D printing in construction.

Adopting MMAM addresses several industry challenges, such as high material costs, energy demands, and stagnant productivity growth. Additionally, traditional construction faces issues with high error rates and skilled labour shortages, compounded by strict tolerance requirements. MMAM can streamline construction by reducing production steps and addressing complexities in joining different materials or components. The primary benefits of extrusion-based MMAM include scalability with additional extrusion units and adaptability to filament, liquid, or paste materials. However, it is limited by its ability to create only sharp material interfaces and fixed material properties.

3. Contour Crafting

3.1. Origin of Contour Crafting

Contour crafting (CC) is one of the most well-known additive manufacturing methods for construction, and it first started the late 1990s. In 1997, a prototype exploration on 3D printing concrete by Joseph Pegna at Rensselaer Polytechnic Institute in New York was created. Pegna's goal was to automate the construction process through using concrete that would generate less waste and be more cost-effective than traditional methods [9].

Building on initial explorations by Pegna, Behrokh Khoshnevis from the University of Southern California developed the technique in 1998 and aptly called it Contour Crafting. This process was groundbreaking in that it employed a computer-controlled crane that laid concrete down in set sequences, ones capable of producing smooth and complex surface contours [10]. This enabled the speed construction of large-scale buildings that maintained uniqueness in a different way from other traditional methods in terms of efficiency and cost-effectiveness [11].

CC was an important development since it expanded the limits set by automation in the construction industry. It is a showcase of how technology can take conventional construction and turn it into a fast, cost-effective process that leaves very minimal environmental footprint.

3.2. Contour crafting construction process

CC construction of a building uses the technology of digital precision combined with conventional construction methods. This is done in the following procedure as explained below.

Design and planning: The process of construction starts by making a 3D digital model of the building. All architectural information is available and is prepared using software [12].

Site preparation: This covers the tasks of land clearing, levelling, and foundation preparation before the actual construction takes off. All the steps remain based on traditional construction to ensure structural solidity [13].

Printer Setup: This is an important phase in contour crafting. The printer, shaped as a big crane with a nozzle attached, is transported to the site and assembled. The technicians get it ready for placement and calibration to follow the digital model of the building, making sure the base of the printer is secured, and the nozzle of the extrusion is aligned accordingly [14].

Structural foundation: The CC can manage wall construction, most of the foundations require conventional techniques such as pouring concrete [15].

Structural printing: This includes extruding concrete or other composite materials in layers by a contour crafting robot to construct the walls and façade of a building. The robot prints material exactly as required by the digital model. Traditional methods can be simultaneously used to install reinforcing bars, create door and window openings, and integrate utilities [12], [13].

Interior setup and systems integration: When printing of the main structure is complete, interior activities including electrical, plumbing, and HVAC (heating ventilation and air-conditioning) installation take place. Traditional construction workers execute these tasks while using the output from the digital machine to ensure everything fits well [16].

Roof and finishing touches: The roof can be printed if the structure and design permit, or it may be done using traditional means. Finally, doors, windows, and any finishing touches such as painting and flooring can be installed [13].

3.3. Setting up the 'printer'

The process of establishing a CC printer includes the following major stages:

Transportation and assembly: The printer arrives on site as a kit that is assembled. For the gantry model, this includes building the gantry system and securing the printer to a level base [14].

Calibration: It involves proper calibration. The rails and nozzle are aligned with accurate alignment so that material is correctly deposited in layers [14].

Integration of software and model: A 3D digital model is uploaded into the printer's control system. Software instructs the path and speed which nozzle should follow so that it precisely achieves the specifications of the design.

Testing: Different types of tests are done prior to actual construction, machine calibration, and model input accuracy for total avoidance of construction errors [17].

The integration of 3D printing with traditional construction therefore requires good coordination between the construction workers and technicians for a successful build.

3.4. How contour crafting is used

The revival of the raw concrete aesthetic of 1950s architecture is now seen in contour crafting, an advanced 3D printing technique offering significant potential for modern construction. This automated method enhances design flexibility, reduces material waste, and speeds up production, making it a promising technology for future architectural projects.

CC constructs both exterior and interior walls as single, unified units rather than assembled sections, promoting efficiency in the production of housing [18]. The technique uses a robotic arm equipped with an extrusion nozzle, layering material to form diverse shapes. Initially limited to concrete, CC now suited for reinforcement fibres, additives, and mortar-based mixes, allowing greater versatility. There are two primary forms of concrete AM: gantry systems, which operate like Cartesian printers along XYZ axes for larger structures, and robotic arm systems, which are vertically mounted for greater mobility and ideal for complex geometries.

This approach scales automated fabrication from small industrial parts to entire buildings, driven by the need for faster and more efficient construction processes. Increasingly adopted by companies worldwide, CC benefits from high-speed production and versatile nozzle configurations that influence material texture and finish. Besides this, AM is viewed as a transformative technology for construction, offering expanded design possibilities and customization options that conventional methods lack.

Cement based materials often bonded and adjustable in curing, are well-suited to extrusion processes [19]. In particular, refractory castable who are comparable to ultra-high-performance concretes show potential due to their complex composition and low water requirements. However, these materials rely on suitable additives to optimize fluidity and rheology, essential for their practical application in construction. Unfortunately, it is still a long way off, though, is the integration of 3D printing into regular construction operations [20]. This could be explained by the building industry's conservative and risk-averse culture as well as current social, technological, and financial difficulties. In addition, although widely accepted in the community, the advantages that contour crafting can offer have not yet been fully investigated and measured.

3.5. Materials and use for contour crafting.

Making a concrete combination that could meet the required qualities be they strength, stiffness, or buildability was one of the challenges [21]. The materials commonly used in this approach include geopolymer concrete and cementitious materials, with sulphur concrete being particularly notable due to its suitability for terrestrial and planetary applications [22]. But also, other paste-based materials like these present challenges. They tend to compress and solidify slowly under gravity, making it difficult to create specific shapes, especially curved forms [23]. To add designers have introduced rapid drying devices on robotic arms or added quick setting chemicals to enhance solidification and layer stability.

Despite these challenges, recent advances in paste-based AM show promise for sustainable construction. Projects like WASP’s Big Delta and IAAC’s Pylos illustrate how clay can be used for rapid, cost-effective large-scale structures. For 3D printing concrete, both cement-based and geopolymer options are used, often incorporating industrial byproducts such as fly ash, silica fume, and slag, which enhance sustainability [20]. Based on the results, it can be concluded that contour crafting is a more desirable method for building non-repetitive freeform concrete structures because its potential environmental benefits increase with building complexity and decrease with formwork reuse times, compared to conventional techniques.

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4. Barriers for making 3D printed buildings commercially available

As mentioned earlier, the use of 3D printing is not yet common in the construction sector, despite the many benefits it could offer. Although it has been a hot topic for a number of years and, little has been realized apart from a few bridges and some simple constructions. Fully realizing homes using 3D printing is still too big a challenge. In this section some barriers to implementing 3D printing in mainstream architecture and construction are presented.

Concrete and layers

Concrete needs to harden faster when it is 3D printed, than in traditional building methods, because it needs to be hard enough in order to carry the weight of the next layer [24]. On the other hand, it needs to bond with the next layer to create a stronger structure[25], which makes it a difficult balance to find. If this is not done correctly, cracks can easily form, and the formed concrete structure will not meet the quality requirements [26] . Cracks can also form when layers of concrete harden unevenly, due to fluctuating temperature differences. This can also lead to local differences in strength. Because concrete used in 3D printing often has problems with strength, it is often the case that only one level of a building can be printed [27].

Additionally, because concrete is made of certain mixtures to maintain the right consistency, it is often much more expensive than the casting of concrete, which is used in traditional construction methods [28].

Complex systems and regulations

Different types of structures and mechanisms need to be implemented in a building. For example, it is common for a building to normally use a sandwich-wall structure, in which a wall consists of 3 layers: the inner wall, a layer of insulation and an outer wall. Also, elements such as HVAC, electricity, and internet connectivity need to be taken into account when constructing. This is not easy to do when CC is used as a construction method [28]. Therefore, CC developers should first study how this technology would be managed at a construction site. Standards must be developed to regulate the use and management of CC, when this will become the standard construction method [21].

There are many requirements that buildings must meet, also in the area of safety. Because CC is still relatively new and not often used, strict regulations have been drawn up to ensure safety. In addition, these regulations are constantly being changed, which make it more challenging to meet compliance standards [28].

Design and scale

Concrete that is created as a whole by casting always has a flat, straight shape. With CC it is possible to create different types of dynamic shapes, but the layers are often clearly visible, which can have an aesthetic disadvantage. When designing a building, the dimensions of the printer must also be taken into account. The size of a building depends on the size of the printer, which can give certain design restrictions [26].

Labour

While less labour is needed to manually build the houses, there are still skilled workers needed to assemble the printer. The printer must also be properly maintained, and any malfunctions must be remedied in a timely manner [29] . Also, besides the wall printing, many other systems need to be installed manually, like the HVAC, electricity and internet connectivity.

5. Conclusion

In many sectors automated systems are taken over tasks, this will also happen in the near future of construction and architecture. But before that happens on a larger scale more investigation and norms how to use and implement this system in today's construction sites is needed. Contour crafting is a promising additive manufacturing technique due to automate, reduction in material waste and the fast construction of complex structures. From digital models contour crafting is able to fabricate load bearing walls and building shells, in a fast and efficient way. This could for example be used for affordable housing and emergency shelter. For architects it allows much design flexibility and custom shapes without the need of traditional moulds.

However, contour crafting has not yet reached this stage, where a number of factors are crucial. One of them is the need for rapid hardening of the concrete formulations that balance bonding and structural integrity and also fit through the nozzle. Another challenge is the integration with complex systems and navigating evolving regulatory standards. But CC is positioned as a revolutionary building method due to its sustainable and scalable approach, particularly for non-repetitive, freeform structures. With the continuing future developments contour crafting could be a workable and ecofriendly method than that of the conventional system. Especially in the field of architecture for complex and customized designs.

References

[1] A. L. M. Tobi, S. A. Omar, Z. Yehia, S. Al-Ojaili, A. Hashim, and O. Orhan, "Cost viability of 3D printed house in UK," IOP Conf Ser Mater Sci Eng, vol. 319, no. 1, p. 012061, Mar. 2018, doi: 10.1088/1757-899X/319/1/012061.

[2] M. Žujović, R. Obradović, I. Rakonjac, and J. Milošević, "3D Printing Technologies in Architectural Design and Construction: A Systematic Literature Review," Buildings 2022, Vol. 12, Page 1319, vol. 12, no. 9, p. 1319, Aug. 2022, doi: 10.3390/BUILDINGS12091319.

[3] T. Chu, S. Park, and K. Fu, "3D printing-enabled advanced electrode architecture design," Carbon Energy, vol. 3, no. 3, pp. 424–439, Jul. 2021, doi: 10.1002/CEY2.114.

[4] R. Mathur, "3D Printing in Architecture," IJISET-International Journal of Innovative Science, Engineering & Technology, vol.

3, 2016, Accessed: Nov. 04, 2024. [Online]. Available: www.ijiset.com

[5] Nora Soualhi, "3D Printing in Construction: Review on Processes, Materials mix, and Energy Performance ," 2021, Accessed: Nov. 09, 2024. [Online]. Available: https://d1wqtxts1xzle7.cloudfront.net/78457451/3D_Printing_Nora-libre.pdf

[6] J. ZHU, H. ZHOU, C. WANG, L. ZHOU, S. YUAN, and W. ZHANG, "A review of topology optimization for additive manufacturing: Status and challenges," Chinese Journal of Aeronautics, vol. 34, no. 1, pp. 91–110, Jan. 2021, doi: 10.1016/J.CJA.2020.09.020.

[7] Y. M. Xie, "Generalized topology optimization for architectural design," Architectural Intelligence 2022 1:1, vol. 1, no. 1, pp. 1–11, Jun. 2022, doi: 10.1007/S44223-022-00003-Y.

[8] A. Pajonk, A. Prieto, U. Blum, and U. Knaack, "Multi-material additive manufacturing in architecture and construction: A review," Journal of Building Engineering, vol. 45, p. 103603, Jan. 2022, doi: 10.1016/J.JOBE.2021.103603.

[9] J. Pegna, "Exploratory investigation of solid freeform construction," Autom Constr, vol. 5, no. 5, pp. 427–437, Feb. 1997, doi: 10.1016/S0926-5805(96)00166-5.

[10] Anon, "Innovative rapid prototyping process makes large sized, smooth surfaced complex shapes in a wide variety of materials," Materials Technology, vol. 13, no. 2, pp. 53–56, 1998,

[11] F. Lyu, D. Zhao, X. Hou, L. Sun, and Q. Zhang, "Overview of the Development of 3D-Printing Concrete: A Review," Applied Sciences 2021, Vol. 11, Page 9822, vol. 11, no. 21, p. 9822, Oct. 2021, doi: 10.3390/APP11219822.

[12] B. Khoshnevis, D. Hwang, K. T. Yao, and Z. Yeh, "Mega-scale fabrication by Contour Crafting," International Journal of Industrial and Systems Engineering, vol. 1, no. 3, pp. 301–320, 2006, doi: 10.1504/IJISE.2006.009791.

[13] S. Lim, "Fabricating construction components using layer manufacturing technology | Request PDF." Accessed: Nov. 08, 2024. [Online]. Available: https://www.researchgate.net/publication/312919469_Fabricating_construction_components_using_layer_manufacturing_technology

[14] M. Sovetova and J. Kaiser Calautit, "Thermal and energy efficiency in 3D-printed buildings: Review of geometric design, materials and printing processes," Energy Build, vol. 323, p. 114731, Nov. 2024,

[15] S. H. Ghaffar, J. Corker, and M. Fan, "Additive manufacturing technology and its implementation in construction as an eco-innovative solution," Autom Constr, vol. 93, pp. 1–11, Sep. 2018, doi: 10.1016/J.AUTCON.2018.05.005.

[16] J. Van Der Putten, M. Deprez, V. Cnudde, G. De Schutter, and K. Van Tittelboom, "Microstructural Characterization of 3D Printed Cementitious Materials," Materials 2019, Vol. 12, Page 2993, vol. 12, no. 18, p. 2993, Sep. 2019, doi: 10.3390/MA12182993.

[17] F. Bos, R. Wolfs, Z. Ahmed, and T. Salet, "Additive manufacturing of concrete in construction: potentials and challenges of 3D concrete printing," Virtual Phys Prototyp, vol. 11, no. 3, pp. 209–225, Jul. 2016, doi: 10.1080/17452759.2016.1209867.

[18] M. Bilal, "A Review of Internet of Things Architecture, Technologies and Analysis Smartphone-based Attacks Against 3D printers," Jun. 2017, Accessed: Nov. 08, 2024. [Online]. Available: http://arxiv.org/abs/1708.04560

[19] L. H. F. Z. S. K. O. Klein, "3DK Competence Center Investigates the Potentials of Contour Crafting," InterCeram: International Ceramic Review, 2021.

[20] S. Liu, B. Lu, H. Li, Z. Pan, J. Jiang, and S. Qian, "A comparative study on environmental performance of 3D printing and conventional casting of concrete products with industrial wastes," Chemosphere, vol. 298, p. 134310, Jul. 2022, doi: 10.1016/J.CHEMOSPHERE.2022.134310.

[21] G. Fernandes and L. Feitosa, "Impact of Contour Crafting on Civil Engineering ." Accessed: Nov. 08, 2024. [Online]. Available: https://d1wqtxts1xzle7.cloudfront.net/63372189/impact-of-contour-crafting-on-civil-engineering-IJERTV4IS08059320200520-28639-1grvl8-libre.pdf

[22] B. Khoshnevis, X. Yuan, B. Zahiri, J. Zhang, and B. Xia, "Construction by contour crafting using sulfur concrete with planetary applications," Rapid Prototyp J, vol. 22, no. 5, pp. 848–856, 2016,

[23] P. F. Yuan and L. Gong, "Digital Ceramics: High hyperbolic curvature fabrication technologies in paste-based additive manufacturing," 2023, Accessed: Nov. 09, 2024. https://www.ingentaconnect.com/contentone/iass/piass/2023/00002023/00000025/art00007#

[24] M. G. Aboelhassan, "Future of Sustainable Construction Industry: A Review of Research, Practice and Applications of 3D Concrete Printing," Advancements in Civil Engineering & Technology, vol. 5, no. 4, Jan. 2023, doi: 10.31031/ACET.2023.05.000616.

[25] H. Tu, Z. Wei, A. Bahrami, N. Ben Kahla, A. Ahmad, and Y. O. Özkılıç, "Recent advancements and future trends in 3D concrete printing using waste materials," Developments in the Built Environment, vol. 16, p. 100187, Dec. 2023, doi: 10.1016/J.DIBE.2023.100187.

[26] G. van Bakel, "Advantages and disadvantages of 3D printed concrete in comparison to conventional concrete manufacturing methods." https://www.academia.edu/40316619/Advantages_and_disadvantages_of_3D_printed_concrete_in_comparison_to_conventional_concrete_manufacturing_methods

[27] A. Kazemian, "CONTOUR CRAFTING: A REVOLUTIONARY PLATFORM TECHNOLOGY.". https://www.researchgate.net/publication/354138382_CONTOUR_CRAFTING_A_REVOLUTIONARY_PLATFORM_TECHNOLOGY

[28] J. Punkki, "3D-printed concrete: still in its infancy - Elematic precast technology." Accessed: Nov. 10, 2024. [Online]. Available: https://www.elematic.com/concrete-issues/3d-printed-concrete-still-in-its-infancy/

[29] S. J. Schuldt, J. A. Jagoda, A. J. Hoisington, and J. D. Delorit, "A systematic review and analysis of the viability of 3D-printed construction in remote environments," Autom Constr, vol. 125, p. 103642, May 2021, doi: 10.1016/J.AUTCON.2021.103642.

AI Disclaimer

During the preparation of this work, we used Word and Grammarly to aid with spelling and grammar checks, avoiding complete rewriting, or changing the writing style, tone, or structure of the text. After using these tools, we reviewed and edited the content as needed, and we take full responsibility for the final content. Additionally, we used Google Translate to translate specific words from Dutch to English when we were unable to recall them at the moment. Signed,

Krijn Blommestijn
Mariska Geelhoed
Dennis Klappe