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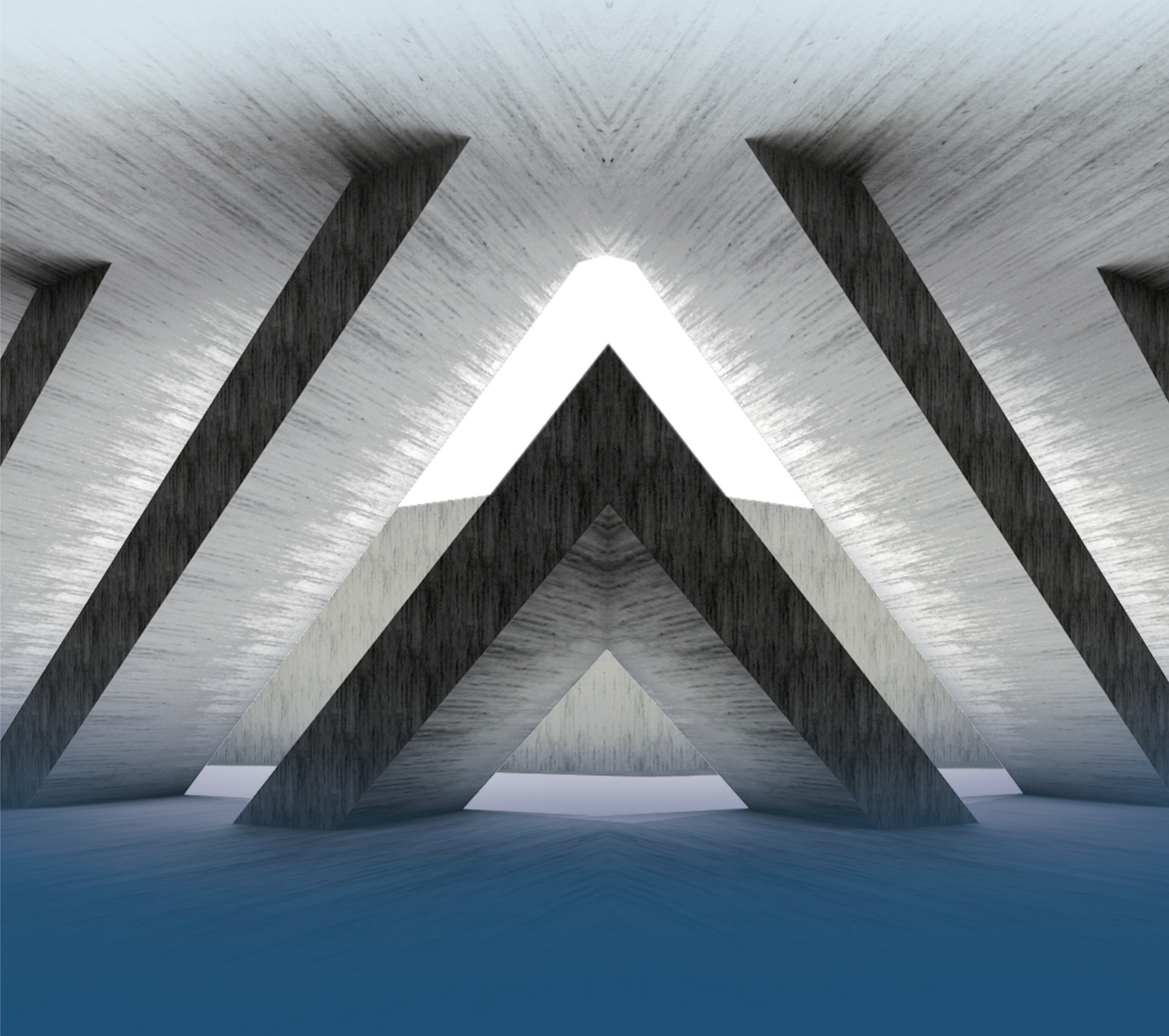

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Best Practices in Construction 4.0: Catalysts of Digital Innovations (Part I)

Bianca Weber-Lewerenz**, *Marzia Traverso

Institute of Sustainability in Civil Engineering (INaB), RWTH Aachen University, 52062, Germany

ABSTRACT

Digital transformation in the AEC industry (Architecture, Engineering and Construction) is a key driver to enhance technical innovation in the branch and adds dynamic to all work processes and methods. A more differentiated understanding of the responsible use of innovative technologies aims not only towards increased technical, environmental, educational, societal and gender equality sustainability and more efficient building life cycles but also to recognize the unintended effects such as artificial intelligence (AI). The study is part of a larger primary research on Corporate Digital Responsibility (CDR) in Construction 4.0. This identifies, analyzes and systematically evaluates key factors of a sustainable digital transformation, especially in the traditionally small-scale Construction Industry, in which there can be no standardized procedure. The study uses interdisciplinary literature and data research and expert interviews. The qualitative method enables a critical-reflexive analysis of the key factors of meaningful and sustainable implementation of innovative technologies in Construction. Application examples show possible approaches, some of which are implemented as prototypes and provide guidance for small to medium-sized companies. The study outlines the necessary steps for companies to define their own potential fields of application and find suitable methods. Another aim of the study is to take stock of the acceptance of new technologies by comparing different perspectives from experts. The study results show new perspectives on the transformation of the Construction Industry. They show that Digital Transformation in Construction 4.0 has great potential for an economical, efficient construction life cycle, but requires the responsible, sensible use of innovative technologies.

Keywords: Digitization; AI; Digital transformation; CDR best practices; Digital innovation; Smart cities

*CORRESPONDING AUTHOR:
Bianca Weber-Lewerenz, Institute of Sustainability in Civil Engineering (INaB), RWTH Aachen University, 52062, Germany; Email: bianca.christina@gmx.de

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1. Introduction

The building sector causes almost 40% of global CO_2 emissions. Buildings are responsible for around 40% of energy consumption and 36% of CO_2 emissions in the EU [1]. The Construction Industry is the largest branch of the economy. Thus, this sector is not only the key to the EU's climate neutrality by 2050 [2], but also bears significantly high responsibility for strengthening the social, economic and ecological pillars of sustainability [3] (**Figure 1**).

Such a profound process of change implies a high level of social responsibility, beyond the digital age. *All actors involved in construction...*are*...required to fundamentally rethink technical progress in construction* [4].

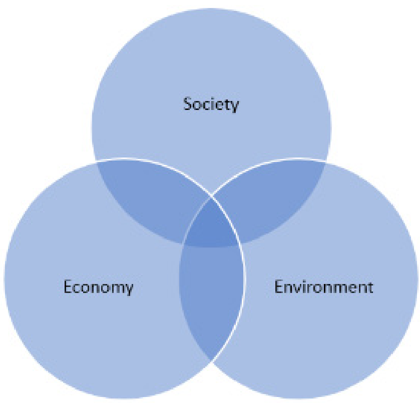

Figure 1. Basic pillars of sustainability, transferable to construction.

Source: Bianca Weber-Lewerenz.

Thanks to innovative digital technologies and AI, the Construction Industry experiences changes with major impacts on work processes, people, society as a whole, as well as on the environment and climate. AI in Construction means replicating cognitive properties such as human learning and thinking to use this technology to structure the increasing data complexity, avoid data loss, make construction sites and processes safer and consistently controllable. AI enables a significant increase in efficiency, a reduction in resource consumption and, thus, the achievement of sustainability goals set by the UN. This is a more serious problem for a technology like AI in the context of the Construction Industry, an industry that has traditionally lagged behind advanced technology compared to others. In the absence of proven performance and under pressure to deliver projects on time and on budget, this branch continues to use methods traditionally trusted. This lack of confidence to adopt new workflows is deeply rooted in technical and psychological factors. Trusted AI is a relatively new research paradigm and can be seen as an enabler that catalyzes trust [5]. The necessary human change strengthens innovation and the application of new technologies [6,7]. In this context, one speaks of Baukultur 4.0: What is meant is the value-based Construction Industry 4.0, that drives forward sustainable action in the sense of the common good. It describes the sum of services that people contribute to shaping the digital age, taking into account the social, ecological, economic and aesthetic dimensions and creating an environment that is perceived as worth living in. In its "White Paper on Artificial Intelligence" in 2020 [8], the EU Commission called for the consideration and protection of values and fundamental rights, the careful distinction between machine and human intelligence and careful handling of AI. The study shows that holistic research is needed to consider the unintended consequences in the next research agenda [9,10]. The "dark" side of new innovative technologies includes the social impact of overuse, human dependency, security and privacy concerns, prejudices such as gender bias and inequality, but also ecological impacts on the raw materials sector. After all, it is difficult to decouple economic and technological growth from resource consumption.

The previous primary study led to the concept of Corporate Digital Responsibility (CDR) in Construction, which aims to define the key factors of sustainability in the digital age. CDR has already been established in other disciplines [11,12]. These findings not only represent novel insights and increase knowledge, but also increase the understanding of the benefits for the Construction Industry and offer concrete design approaches. The results of the expert surveys and literature research demonstrate that new technologies are finding their way into all planning and operational processes and that interfaces are increasingly being researched across disciplines [13]. Small, medium and large companies are looking for advantages and added value in order to be able to apply the new technologies that are required to achieve sustainability goals. The aimed added value of these innovative technologies stretches from the more economical execution of projects, the increase in climate protection and sustainability from higher occupational safety, the handing over of routine processes to machines. Research is being carried out on practical solutions in the design of digital transformation and AI [14,15]. Best practices are the first signposts for the trustful, sustainable use of digitization and AI. Against the background that many small to medium-sized companies are still struggling to implement their own needs in digital transformation, such as operational efficiency and optimization of employee productivity, and there are still complex obstacles such as employee qualification and financial investments, practical examples in particular offer orientation and strengthening of the willingness to innovate. The exchange of knowledge between research and practice creates a practical approach.

The study by the Fraunhofer Institute for Industrial Engineering (IAO) on AI in Construction, in cooperation with one of the authors, highlights for the first time the AI technologies that are already being used in practice and the ethical observations made [16]. AI is still in the development stage, with companies and engineering firms looking for their own advantages to increase competitiveness and generate new orders [17]. Practical application experiences show how these new technologies relieve people in a meaningful way and help to make data communication and work processes more efficient and secure. In the expert surveys, some German locations have proven to be leaders in the development, application and research of AI in the Construction Industry. These role models are innovation champions providing orientation along the digital transformation process through the use of innovative technologies that lead to sustainable building life cycles and resilient ecosystems [18].

Best practices inspire others and drive them to innovate in the future. This primary study uses the qualitative method with interview surveys and a structured literature analysis. The study, which takes a closer look at the practical fields of application, examines the status quo, trends and defines the missing framework conditions that are necessary for a "healthy" human-technology interaction [19], the development of constructive approaches in practical application and the increase in the shares in the value chain. With her new field of research, the first author wants to anchor the Construction Industry in the interdisciplinary scientific debate. Innovative technologies are catalyzing the design of Construction Industry 4.0; but only the corresponding organizational and human transformation enable technical change and offer a framework for orientation.

The increasing awareness in the Construction Industry for balanced, sustainable human-machine interaction is noticeable, as the interviewed experts confirm. The research results from Technology Ethics and Technology Assessment by Armin Grunwald, Hans Jonas and Christoph Hubig, Practical and Technology Philosophy, Ethical Engineer Responsibility in Construction underline additionally. The technical discussion provides insights into entrepreneurial success stories [20,21]. The first author's articles in specialist journals substantiate the potential for more sustainability and added value [22,23]. Her book "*Accents of Added Value in Construction 4.0*" (published in December 2022) focuses on the corporate responsible use of digitization and AI in the Construction Industry with the associated ethical observations. The results of the expert interviews led to the conclusion that corporate digital responsibility assumes sensible technical application to achieve resource-saving construction life cycles from project ideas to dismantling and re-use, without neglecting the protection of personal and data rights.

Digital project orders require adequate corporate digital project infrastructure, because clients increasingly trust in and award contracts to companies that have a digital communication infrastructure and use the invested budget economically. The focus tends to move away from pure orientation on the offer price towards sustainability aspects, for example through new award criteria and adjustments of contractual regulations. The expectations of AI in the Construction Industry are high: Standardized processes executed by machines, structure of increasing data complexity, cost-and time-efficient, resource-saving construction, monitoring and fulfillment of climate goals, to implement the UN Sustainable Development Goals (SDGs). The central corporate expectations consist of the expansion of digitization, greater efficiency at lower costs, agility and resilience.

This raises the question of how we humans want to design this technology. The experts surveyed believe that trust can only be created and the right path for the company found in digital change f the appropriate curricula and professional qualifications are given and technologies made explainable. Interviewed AI software developers can then provide the best possible support, advice and potential fields of application for SMEs if they can localize their own needs and define expected advantages: The SMEs already have extensive data that can be used. The scope of costs is kept within reasonable limits, as consultancy and support are provided by startups, often by young company founders. These do not re-explore AI, but inistead offer customized solution packages with AI tools for the company. These cost-time-efficient cooperations are still in their infancy, and therefore make the most sense for taking the first steps in trying out digital technologies and AI as a company or engineering office—at no financial risk. New digital business models can be developed to strengthen the own role of being a competitive partner and to work out solutions on a highly customer-oriented basis. Interviewed start-ups and IT consultants recommend taking advantage of the financial support offered by the state specifically for AI projects. Strong network groups ensure mutual entrepreneurial support when getting started.

One of the most important results of the study is that, in addition to explainability, potential new binding regulations for the sensible use of AI and as a signpost are seen as requirements. In addition, the surveyed group of experts repeatedly addresses the fact that the education system and curricula require profound adjustments to ensure that the next generation of engineers and specialists are equipped with advanced knowledge of digitization and AI, as well as the necessary ethical qualifications and able to perform close, interdisciplinary interface work that is increasingly necessary to combine professional strengths.

In the digital transformation, companies have the unique opportunity to increase their attractiveness as employers. In the interviews, it becomes clear: The digital transformation in Construction is a process that everyone, not just individuals, is called for action. Waiting or the attitude "we don't need it, it's working" should belong to the past in this industry-wide process. The greatest challenge is to be open towards innovative technologies and to build up step-by-step the required professional and personal qualifications.

AI applications already implemented in practice range from structural and civil engineering, technical building automation, monument preservation, formwork and tunnel technology, timber construction, fire protection and smart cities. As the survey results show, the greatest challenge consists in developing a digital agenda that suits the company and defining the fields of application of AI in Construction Industry [24,25].

While Part I of this article deals with practical examples of success and key factors for sustainably successful digital innovations, Part II of the article deals with the "dark" side of digitization, which is—especially in the scientific research-recommended as integral part of the guide.

2. Materials and methods

The study is part of a larger primary research and uses the qualitative method [26]. 50 expert interviews were conducted over a period from 2019 to 2021. A comprehensive literature and database research was implemented with a structured literature analysis (**Figure 2**), supplemented by interviews with selected interdisciplinary experts, with a response rate of 90% (**Figure 3**).

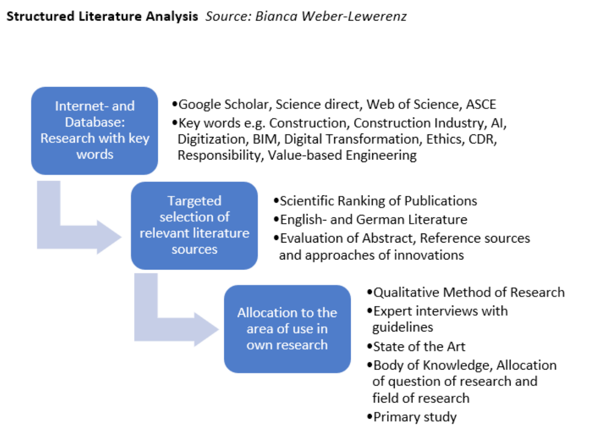

Figure 2. Structured literature analysis.

Source: Bianca Weber-Lewerenz.

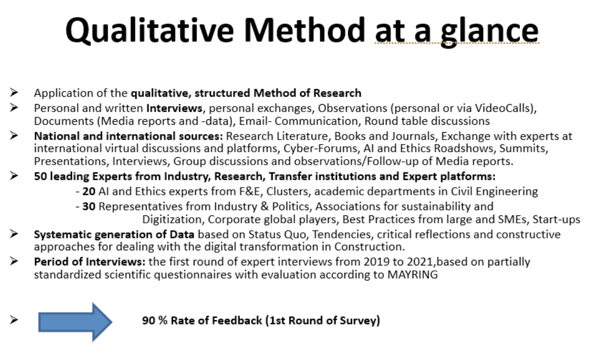

Figure 3. Qualitative method.

Source: Bianca Weber-Lewerenz.

The interview surveys are based on partially structured scientific questionnaires and field notes. In addition to experts in companies from the fields of innovation, digitization, technology development, representatives of German and international civil engineering associations, chambers of crafts and construction associations, departments in ministries that were set up specifically for digital transformation, research and educational institutions, institutes for ethics and AI were involved. Their shared experience, including observations on the lack of framework conditions, contributes to the systematic generation of data. Well-founded knowledge about motives for action, needs and their critical reflections helped to develop constructive approaches. Literature sources in other disciplines, that deal with similar research questions, proved to be particularly informative for the Construction Industry [27-29]. Here, the study aims to anchor the Construction Industry in the interdisciplinary scientific debate led by trustworthy AI.

The Internet search for the terms Construction, AI, Digital Transformation and Ethics resulted in the publications of the author appearing immediately, who is specifically dedicated to this interdisciplinary interface research. Other sources of literature are either dedicated only to certain areas or too far from the subject. However, these new scientific literature sources offer important access to further research.

AI methods in large and small companies and in medium-sized companies are still in a very early implementation phase. The research field is new territory and AI is increasingly being used for research purposes in test runs. Therefore, recommendations and observed trends that experts consider important for the bigger picture and share in the interview surveys make up a majority of the responses. Expert interview surveys were designed and conducted to gain more information on implementation projects of digitization and AI in companies in the Construction Industry. This allows approaches to be derived as to how companies can be better supported in the development and introduction of their own digitization strategy, and which necessary framework conditions are to be determined. In the scientific investigation, the insider knowledge of the experts on processes and decision-making structures within an organization is of particular interest.

Open questions enabled us to critically investigate the status quo, to define barriers, and to obtain empirical values and personal assessments—evaluated against the background of explicitly stated criteria, such as e.g. the compatibility with social values and sustainability. These include, in particular, environmental compatibility and a humane, sensible implementation. For the selection of the interviewed experts, the design of the interview survey and questions with categorization, the question of the research work was largely guided by the previously determined objective of the investigation in the new research field: *Where is corporate digital responsibility (CDR) to be assigned and how shall an adequate ethical framework be designed to support digital innovations in order to fully exploit the potential of digitization and AI?*

An excerpt of the interview questions shows how this new field of research was approached:

1) How do you assess the status quo of digitization and artificial intelligence (AI) in the construction industry?

2) How great is the need for information on digitization and AI? (Scale 1-10)

3) Do you use these? If yes, what are your experiences?

4) What risks and problems do you see in the use of digitization and AI?

5) Where do you see the potential of ethical frameworks and standards for the use of digital technologies and AI in construction?

6) Is it important to regulate the ethical framework by law? (Scale 1-10)

7) Where do you see areas of application for digitization and artificial intelligence (AI) in the construction industry?

8) Your company is increasingly using digital methods and AI. What ethical standards and framework conditions do you think are necessary for responsive handling in construction companies, especially with data?

9) How high do you estimate the need for new digitization technologies and AI in construction? (Scale 1-10)

10) And what are the most important skills of engineers—professionally and personally—to successfully face the challenges of digital transformation?

11) What limits and risks does a company experience when implementing digitization and what opportunities arise? (e.g. in the areas of technology, people and specialists, corporate structure, ethics, mission statement, law, politics, etc.)

The basis of the considerations is an identical interdisciplinary environment, as the research question itself addresses: These are the theories and approaches from Human-Technology Interaction, Ethics in AI and Robotics [30,31], Technology Ethics, Digital Ethics, Philosophy, Social Ethics, but also Business Ethics. These technically diverse perspectives help to answer the research question holistically at this interface. In order to give the research field a name and to promote its expansion [32-34], the author founded the "*Excellence Initiative for Sustainable, Human-Led AI in Construction*" in 2020.

Ethical questions in the digital change in the Construction Industry raise in the field of social and environmental responsibility: Climate and environmental problems are recognized, but the potential for long-term cost savings, the achievement of sustainable development goals and the expansion of the value chain through digital corporate responsibility, which is supported by a lived culture of values are guided by ethical principles, but only used to a limited extent [35]. In order to achieve sustainable innovations such as digital methods and AI, ethical decision-making processes should be institutionalized in corporate culture worldwide [36].

3. Best practices—Key competence "AI—Made in Germany". Challenges and innovation champions

The study extends the current body of knowledge with new insights on the acceptance of new technologies such as AI through practical use cases, and on how new technologies are already being used responsibly. Examples consist of the targeted structuring of complex data and image and object recognition by AI, which significantly simplifies processes in planning, implementation, monitoring and logistics. Further examples representing the use of digital methods with the help of the digital twin are the visualization of the planned end product with its technical equipment with a simulation of user behavior and energy consumption, possible risks, environmental and social impacts and intelligent communication, e.g., in Smart Cities. Some companies are pioneers in the end-to-end digitization of all processes, in visual object identification and in the automation of engineering tasks. The term Best Practice has also become firmly established in scientific publications. This refers to application examples that act as role models by sharing the experiences they have already gained and encouraging other companies to define their innovative path, taking into account their own potential and the challenges they face. There are no instructions or manuals that serve as a generally valid template for action or as the only correct way.

3.1 Best practice WAYSS & FREYTAG, PERI, APLEONA

In the interview surveys, companies share the state of the technology based on experience in implementation and provide estimated tendencies and outlooks. The first prototypes of AI solutions have been created (**Figure 4**). In 2020, interviewed digitalization experts in companies forecasted 12 to 24 months for the operationalization phase. There are potential and already concretely implemented areas of application for digital methods and AI. They enable digital online construction site inspections with VR glasses, simulation of renovation, acoustic and fire protection concepts, AI-supported sensors for detecting and detecting defects/damage and monitoring of installed concrete (e.g. PERI), AI monitoring and controlling of the construction progress, forecasting and strategy data systems as a basis for entrepreneurial decision-making (predictive technologies). Technologies that use AI, such as 10D twins, offer a real-time display of time and costs as construction progresses. The effects of planning changes can be demonstrated to the customer; more transparency and illustration strengthen customer trust and ensure corporate compliance. The interviewed experts consider one of the most important advantages, the more sustainable, resource-saving, energy-efficient and environmentally friendly work throughout the entire construction life cycle in the innovative technologies in Construction. Highlighted examples underline the practical cases of application.

PERI is working on two subject areas for possible pioneering fields of application of AI: 1) Visual object identification and 2) Automation of engineering tasks. In an interview conducted with the author PERI`s Chief of Digital Transformation & Corporate Development, explains more about this: Neural networks enable part recognition on construction sites. Prototypes in test phases already exist here: Instead of the previous QR codes on the material, RFID chips and image recognition localize the building material via GPS transmitters. In the area of engineering automation, we try to solve the engineering tasks in a data-driven manner using historical data and the use of appropriate models. We are still reaching the limits of computing capacity. Stadel estimates the potential of AI fields of application in the entire building/object life cycle of a structure to be very high; Technical Building Automation, Facility Management in particular could perform more efficiently: AI applied in hazard detection via sensors, tunnel construction, bridge construction (e.g., collapse in Genoa), developing logic for data evaluation for automation/robotics, minimizing hazards, could shape construction sites safer and smarter.

PERI, Wayss & Freytag, APLEONA and other construction companies emphasize the search for meaningful fields of application of AI, geared towards the benefits for everyone involved in the process. This is seen as the mission-critical path of digital transformation of the Construction Industry.

The study identifies the willingness to change and costs for innovations as the biggest barriers that companies encounter in digitization and AI - both investments in the future and part of change management. The industry is traditionally highly fragmented, each company tests individually, smaller companies often lack the financial background, large corporations are sufficiently financially strong for research and development. They often have independent departments and their own research. The fragmentation of the trades represents a major challenge.

Access to a uniform data platform of the model is guaranteed for all project participants with end devices at any time, from any location, without data loss. The BIM extended with AI therefore seems to make sense in the first step, as AI experts confirm. For Wayss & Freytag Ingenieurbau, the biggest obstacles to the use of AI consist in the lack of consistency in the digital process, time-consuming data management on the construction site, and missing or legally uncovered data security (data availability, further use and use of the data).

Companies	AI-Solutions
APLEONA	**Predictive Maintenance:**
	a) AI-Solution: "full-automized Technical Building Equipment" (Aim: Energy-Monitoring)
	b) AI-Solution: "energyControl" (Aim: Predictive Control)
PERI	**Research on potential application of AI in two fields:**
	a) Visual Object-Identification (Aim: Visual Object Recognition)
	b) Automization of Engineering tasks (Aim: Data-driven solutions of Engineering tasks)
WAYSS & FREYTAG (Subsidary of Royal BAM Group)	a) Workflow up to 7-D consistently through all processes of the project
	b) Modeling: Deep Learning Apporoach in the Modeling Phase e.g. as Basis of (partially) automized identification of parts of the construction as point clouds
	c) Parametric Design (Architecture)
	d) "Generative Design"
	e) Visual Object Recognition
Further Projects	ESKIMO = Research project for AI-Application on construction sites (https://www.eskimo-projekt.de/)
	„VINCI Chronsite Program“ (www.leonard.vinci.com)

Figure 4. Three use cases.

Source: Bianca Weber-Lewerenz.

3.2 Best practice—Research project SDaC—Smart design and construction

With its research project, SDaC aims to reduce resources, apply efficiently and consistently digitized processes offering data transparency in real-time. Innovative technologies offer the best methods for data acquisition, ensuring its high quality, maintaining the desired speed of processes and more security. The SDaC Team noted in the interview with the author, that they are developing a platform that enables organizations in the construction industry to easily access information and use it intelligently with added value. AI as a key solution offers automation of repetitive processes, user feedback increases the quality of forecasts, reduces errors and increases quality, leaves time for creative work and other services, supports decisions and reduces complexity of both data and processes and strengthens corporate competitivity via new digital business models.

The recognized application possibilities of AI range from image and object recognition, awarding, supply chains, planning automation, shortage prediction to deadline forecasts. For example, the target/actual comparison of construction time and construction budget can be monitored in real-time and occupational safety can be increased through AI-based risk detection. The monitoring of construction machines, utilization and capacity per trade enables machine downtimes to be reduced and efficient utilization to be ensured. AI is part of occupational safety and risk management. AI image recognition supports quantification and type recognition of different sleeves and generates measurements with real-time invoicing. Performance deviations are signaled, which significantly improves documentation.

4. Discussion and limitations. Signposts in the digital transformation—Part I

The study, part of a larger primary research on CDR in Construction 4.0, expands the existing knowledge with an overview of the most important key drivers of digital transformation. The changes that the entire value chain in the Construction branch is undergoing affect society and people as a whole. The study provides new insights into value-based approaches in dealing with AI, which accounts for the sustainability of innovative technologies. The research aims to gain the intersection of research trends and developments of national, European and international strategies. The results support future research in the development of a sustainable digital transformation in the Construction sector and getting engaged in the global debate. The central challenge, as this study concludes, is to use the potential of technical feasibility for businesses, to counteract the increased risks of cyber attacks and to ensure the preservation of values and rights. The surveys conclude that innovative and technical progress can only succeed through measures that provide orientation and strengthen the will to innovate in the Construction Industry on the basis of a digital agenda adapted to the company. Best Practices highlight: Responsible corporate design is crucial for the success and sustainability of modern digital technologies and AI.

This research aims at a more sophisticated understanding - beyond technical hype - of how AI is used in practice, taking into account the unintended consequences. An appropriate legal, ethical and technical framework can be derived. Due to the serious impacts on people and society, the study recognizes a strong need: Technical feasibility requires more social responsibility. In order for the construction industry to be able to set its agenda in accordance with the European AI strategy and the UN sustainability goals - according to a derivation of the study results—the discourse must also be conducted here at all political, economic and social levels [37, 38] (**Figure 5**).

Important Milestones of the European AI Strategy
November 2022 – German National Digital Strategy (Part of the International Digital Strategy)
November 2022 - Digital Markets Act DMA (EU)
Oktober 2022 – Digital Services Act DSA (EU)
July 2022 – New European Innovation Agenda (EU)
June 2022 – Strategic Forecast 2022: Interlocking of Green and Digital Change in the new geopolitical context (EU)
November 2021 – AI Act
November 2021 – Digitization Strategy (Coalition Contract 2021)
September 2021 – New Standard IEEE7000-2021. Value-based Engineering.
April 2021 - Promoting a European approach to AI
April 2021 - Proposal for a regulation with harmonized rules for AI
April 2021 - Updated Coordination Plan for AI
October 2020 – 2nd Assembly of the European AI Alliance
February 2020 - White Paper on AI: a European approach to excellence and trust
June 2019 – 1st Assembly of the European AI Alliance
April 2019 – Communication: Building trust in human-centric artificial intelligence
April 2019 – Ethical guidelines for trustworthy AI
December 2018 – Coordination plan on AI ("AI - Made in Europe" - press release)
December 2018 - Stakeholder Consultation: Draft Ethical Guidelines for Trustworthy AI
November 2018 - European Digital Strategy
June 2018 – Launch of the European AI Alliance
June 2018 – Establishment of the High Level Expert Group on AI (AIHLEG)
April 2018 – European AI Strategy (press release "AI for Europe")
April 2018 - Commission Staff Working Document: Liability for Emerging Digital Technologies
April 2018 – Declaration of cooperation on AI

Figure 5. Important milestones of the european AI strategy.

Source: Bianca Weber-Lewerenz.

Innovative technologies enable intelligent, resilient ecosystems, such as Circular Economies, Cradle to Cradle, Smart Cities. All the experts interviewed confirm that the construction industry can only meet its responsibility and exploit technical, social and human potential by overcoming its traditional barriers toward a radical rethink. The critical examination revealed that the social, economic and political influencing factors that innovative technologies bring with them have so far remained unconsidered. CDR in Construction offers such an approach, not only to research ethical and social aspects of technical feasibility, but also to define the framework conditions for a "healthy" human-technology interaction. Despite numerous interdisciplinary types of research, the discourse in the Construction Industry is still hesitant. However, the study encourages such processes through further research. It became apparent that the transfer of knowledge and scientific communication between research and practice is increasingly being recognized as a central lever for raising awareness and the sustainable success of the digital transformation. This study crystallizes the critical path, defines the factors that depend on or influence each other, and focuses on the essentials, namely increasing awareness of one's values when developing and using new technologies. It is becoming increasingly noticeable at all levels and areas of responsibility in the Construction Industry: Innovative technologies are catalysts in shaping Construction 4.0. Virtues and values are more valuable today than ever.

The majority of large and SMEs are looking for their own digitization strategy, often do not have the financial means or feel left behind. The study results show that many companies are in a saturated environment and are benefiting from the success of the past year. You see no need to switch to digitization. It is precisely these companies that exclude themselves from digital project orders because they cannot jump on existing digital project infrastructures. Unable to answer tenders digitally, not being able to handle projects digitally, requiring to first check data in the office instead of a single digital platform accessible whenever and wherever needed and not offering employees a common, uniform digital infrastructure—such companies are not sustainable. Regardless of the size of a company, clients increasingly place their trust in and sign project contracts with modern companies that deal with the invested budget in a responsible, economical, transparent and high-quality manner. These represent selection criteria for graduates and highly qualified workers to select attractive employers to work with.

The cooperation of industry and SMEs with technology start-ups, the formation of regional networks and clusters and exchange of knowledge between research and user practice without language barriers are seen as the most important solutions. Start-ups that localize AI application options and introduce and train the technological solution suitable for the company are particularly suitable for SMEs. The development of knowledge about digitalization and AI and responsible handling offer the key to entrepreneurial success. Times of crisis like the COVID Pandemic prove once again that digitally well-positioned companies are flexible and resilient in their actions and work without significant interruptions.

In order to do justice to their design influence, companies require ethical standards, based on corporate self-commitment.

As the research deepens, the central question remains: How do people and society master this balancing act between technical feasibility and responsibility? What measures must be taken to adapt the existing framework to the new challenges of the digital era? And what are the defined consequences if entrepreneurial self-commitment is not enough?

Sustainability requires a holistic understanding of all influencing factors, in particular the effects on the resources that we need but at the same time want (must) protect. A radical rethink is required for sustainable technical, social and human change in the construction industry. This change could also send an important positive signal for Germany as a forward-looking location for research and teaching in this new scientific field.

5. Results and conclusions

Innovative technologies that are used sensibly and responsibly help the Construction Industry to master the challenges of the digital age more efficiently and sustainably. They foster a multidisciplinary, inclusive environment. CDR represents an essential approach for a balanced human-machine interaction and strengthens a new culture of thinking. The results of the study show that engineers, architects, designers and craftsmen are not only designers of built living environments, but of technical and human change as a whole. Sustainability can only be achieved with the help of an ethical and legal framework that offers orientation in the complexity of technical feasibility and data volumes and protects social and human values. It also requires a radical re-thinking of this traditionally conservative industry.

The evaluation of the interview surveys shows that digital methods and AI bear great potential in many areas, for example setting up competitive, innovative business models. In addition, this industry inherits an important role model function across borders, laying a new foundation with adjusted curricula and data sovereignty.

The study assumes that pioneers in the Construction Industry send strong and positive signals when navigating innovative technologies in Construction 4.0. Given the severe environmental and socio-economic impacts of global challenges not limited to this industry, the Construction Industry around the globe could set a milestone with an innovative agenda. In order to take into account, the entrepreneurial, social, legal and political aspects that are critical to the success of digital transformation, which makes up a significant part of the value chain for the Construction Industry, it is urgent to further expand this new research field. Further research work should be devoted in particular to the protection of data, human rights and diversity, so that security, acceptance and trust can be created among the designers of this branch, which is still very reserved. The study sees the most important approach in setting up a legal framework that is appropriate to the technical feasibility to secure personal rights and data sovereignty.

Future research should work to integrate other trends and key issues into this CDR concept to create a common map of the drivers of digital transformation in construction.

This research bears diverse highlights. The increasing scientific interest has led, among other things, both to a joint study with Fraunhofer Institute on AI in Construction and to the founding of the "*Excellence Initiative for Sustainable, Human-Led AI in Construction*" by the first author in 2020, as well as the research cooperation with the Institute of Sustainability in Construction (INaB) at RWTH Aachen University, Germany. The Initiative provided external scientific support to T20 - Task Force Groups for digital transformation and innovations in 2021, 2022 and 2023 in preparation for the G20—Summit Papers. In December 2022, RESER International Conference awarded the first author with the RESER Founder's Ph.D. award recognizing its scientific contribution. SACAIR, an affiliate of the Centre for AI Research (CAIR), which represents a world-class AI research capacity in South Africa and key multiplicator of this research – for the first time – created two new scientific fields "Socio-technical and human-centered AI" and "Responsible and Ethical AI". The first author`s paper were embedded in the new niche. The first author co-authored the book "Impact of Women Empowerment on SDGs in the Digital Era" which is part of the recent European Council Calls in December 2022 for shaping safe AI as the pillar of the AI Act. In December 2022 she published her two books summarizing this primary research in cooperation with SPRINGER Publishing: "*Accents of Added Value in Construction 4.0—Ethical Observations in Digitization and AI*".

Conflict of Interest

There is no conflict of interest.

References

[1] European Commission, 2020. Im Blickpunkt—Energieeffizienz von Gebäuden (German) [IN focus: Energy Efficiency of Buildings]. Brussels Publishing [Internet] [cited 2022 May 6]. Available from: https://ec.europa.eu/info/news/focus-energy-efficiency-buildings-2020-lut-17_de#:~:text=Insgesamt%20entfallen%20auf%20Geb%C3%A4ude%20in,%2C%20Nutzung%2C%20Renovierung%20und%20Abriss.

[2] European Parlament, 2021. EU-Klimaneutralität bis 2050: Europäisches Parlament erzielt Einigung mit Rat (German) [EU Climate Neutrality until 2050]. Brussels Publishing [Internet] [cited 2022 Dec 17]. Available from: https://www.europarl.europa.eu/news/de/press-room/20210419IPR02302/eu-klimaneutralitat-bis-2050-europaisches-parlament-erzielt-einigung-mit-rat.

[3] Bhattacharya, S., Momaya, K.S., 2021. Actionable strategy framework for digital transformation in AECO industry. Engineering, Construction and Architectural Management. 28(5), 1397-1422. doi: 10.1108/ECAM-07-2020-0587.

[4] Hegger, J., 2020. Konstruktion, Material und Fertigung radikal umdenken (German) [Construction, material and production—A radical rethinking]. Journal Der Bauingenieur. 95(1), A3. doi: 10.37544/0005-6650-2020-02.

[5] Grunwald, A., Hillerbrand, R., 2021. Überblick über die Technikethik (German) [Overview on technical ethics]. Handbook Technical Ethics. J.B. Metzler:Stuttgart. pp. 3-12. doi: 10.1007/978-3-476-04901-8_1.

[6] Mikalef, P., Conboy, K., Lundstrm, J.E., et al., 2022. Thinking responsibly about responsible AI and 'the dark side' of AI. European Journal of Information Systems. 31(3), 257-268. doi: 10.1080/0960085X.2022.2026621.

[7] Obergrießer, M., Kraus, M.A., 2022. Digitale Transformation im Bauwesen—von der Theorie zur Anwendung (German) [Digital transformation in construction]. Masonry Calendar/Mauerwerk Kalender. 47, 499-519. doi: 10.1002/9783433611029.ch16.

[8] European Commission, 2021. Weißbuch zur Künstlichen Intelligenz—ein europäisches Konzept für Exzellenz und Vertrauen (German) [White Paper on AI—A European Concept for Excellence and Trust]. Brussels Publishing [Internet]. Available from: https://wien.arbeiterkammer.at/interessenvertretung/arbeitdigital/EinEuropafuerdasdigitaleZeitalter/DE_Positionspapier_der_Bundesarbeitskammer_zum_Weissbuch_KI.pdf.

[9] Pilgrim, H., 2017. The dark side of digitalization: Will Industry 4.0 create new raw materials demands? PowerShift: Berlin.

[10] Elshkaki, A., Graedel, T.E., Ciacci, L., et al., 2016. Copper demand, supply, and associated energy use to 2050. Journal of Global Environmental Change. 39, 305-315. doi: 10.1016/j.gloenvcha.2016.06.006.

[11] Mueller, B., 2022. Corporate digital responsibility. Journal of Business Information Systems Engineering. 64, 689-700. doi: 10.1007/s12599-022-00760-0.

[12] Wittenberg-Zentrum für Globale Ethik, 2020. Unternehmensverantwortung im digitalen Wan-

del—Ein Debattenbeitrag zu Corporate Digital Responsibility (German) [Corporate responsibility in the Digital Era—A discussion on CDR]. Verlag Bertelsmann Stiftung: Germany. doi: 10.11586/2020063.
[13] Kraus, M.A., Drass, M., Hörsch, B., et al., 2022. Künstliche Intelligenz—multiskale und cross—domäne Synergien von Raumfahrt und Bauwesen (German) [AI—multiscale and cross-domain synergies in space and civil engineering]. BetonKalender 2022. doi: 10.1002/9783433610879.ch9.
[14] Kraus, M.A. et al., 2022. Digitale Transformation und Künstliche Intelligenz—Herausforderungen und Lösungsansätze bei der Kombination von Theorie und Praxis (German) [Digital transformation and AI—challenges and approaches in combining theory and practice]. Ernst & Sohn: Berlin. pp. 168-173.
[15] Charef, R., Alaka, H., Emmitt, S., et al., 2018. Beyond the third dimension of BIM: A systematic review of literature and assessment of professional views. Journal of Building Engineering. 19. 242-257. doi: 10.1016/j.jobe.2018.04.028.
[16] Weber-Lewerenz, B., et al., 2021. AI in Construction in Germany [Internet]. Study by Fraunhofer Institute Stuttgart IAO [cited 2021 Apr 12]. Available from: http://publica.fraunhofer.de/eprints/urn_nbn_de_0011-n-6306697.pdf.
[17] Pan, Y., Zhang, L., 2021. Roles of artificial intelligence in construction engineering and management: A critical review and future trends. Journal of Automation in Construction. 122, 103517. doi: 10.1016/j.autcon.2020.103517.
[18] Goralski, M.A. Tan, T.K., 2019. Artificial intelligence and sustainable development. The International Journal of Management Education. 18(1), 100330sqq. doi: 10.1016/j.ijme.2019.100330.
[19] Grunwald, A., 2010. Technikfolgenabschätzung: Eine Einführung (German) [Technology Assessment: An Introduction]. Edition sigma Publishing: Berlin.
[20] Nikmehr, B., Hosseini, M.R., Martek, I., et al., 2021. Digitalization as a strategic means of achieving sustainable efficiencies in construction management: A critical review. Journal of Sustainability. 13, 5040sqq. doi: 10.3390/su13095040.
[21] Weber-Lewerenz, B., 2022. Technological dream or safety traumata? Fire protection in smart cities-digitization and AI ensure burning ideas and a new culture of thinking in construction 4.0. impact of digital twins in smart cities development. IGI Global Publishing: USA. doi: 10.4018/978-1-6684-3833-6.
[22] Weber-Lewerenz, B., Vasiliu-Feltus, I., 2022. Empowering digital innovation by diverse leadership in ICT—A roadmap to a better value system in computer algorithms. Humanistic Management Journal. 7(1), 117-134. doi: 10.1007/s41463-022-00123-7.
[23] Weber-Lewerenz, B., 2021. Die unternehmerisch verantwortungsvolle Digitalisierung im Bauwesen (German) [CDR in construction]. Journal Bauingenieur. 96(01-02), 19-25. doi: 0.37544/0005-6650-2021-01-02-45.
[24] Feroz, A.K., Zo, H., Chiravuri, A., 2021. Digital transformation and environmental sustainability: A review and research agenda. Journal of Sustainability. 13(3). doi: 10.3390/su13031530.
[25] Ernstsen, S.N., Whyte, J., Thuesen, C., et al., 2021. How innovation champions frame the future: Three visions for digital transformation of construction. Journal of Construction Engineering and Management. 147(1). doi: 10.1061/1943-7862.0001928.
[26] Mayring, P., 2015. Qualitative content analysis: Theoretical background and procedures. Approaches to qualitative research mathematics education. Springer Publishing: Dordrecht. pp. 365-380.
[27] Emaminejad, N., Akhavian, R., 2022. Trustworthy AI and robotics and the implications for the AEC industry: A systematic literature review and future potentials. Journal for Business Computer Science. 139, 104298. doi: 10.1016/j.autcon.2022.104298.
[28] Kaying, W., Fangyu, G., 2022. Towards sustain-

able development through the perspective of construction 4.0: Systematic literature review and bibliometric analysis. Journal of Buildings. 12(10), 1708. doi: 10.3390/xxxxx.

[29] Ågerfalk, P.J., Conboy, K., Crowston, K., et al., 2021. Artificial intelligence in information systems: State of the art and re-search roadmap. Journal for Communications of the Association for Information Systems. 50(1). doi: 10.17705/1CAIS.05017.

[30] Funk, M., 2022. Roboter- und KI-Ethik als philosophische Disziplin (German) [Which rules and regulations do machines have to follow?]. Roboter-und KI-Ethik. Springer Vieweg Publishing: Wiesbaden. pp. 11-22. doi: 10.1007/978-3-658-34666-9_2.

[31] Funk, M., 2022. Welchen Regeln und Gesetzen müssen Maschinen folgen? (German) [Which rules and regulations do machines have to follow]. Roboter-und KI-Ethik. Springer Vieweg Publishing: Wiesbaden. pp. 69-88. doi: 10.1007/978-3-658-34666-9_5.

[32] Weber-Lewerenz, B., et al., 2021. AI in Construction in Germany [Internet]. Study by Fraunhofer Institute Stuttgart IAO [cited 2021 Apr 12]. Available from: http://publica.fraunhofer.de/eprints/urn_nbn_de_0011-n-6306697.pdf.

[33] Weber-Lewerenz, B., 2021. Corporate digital responsibility in construction engineering. International Journal of Responsible Leadership and Ethical Decision-Making (IJRLEDM). 1(3). doi: 10.4018/ijrledm.2020010103.

[34] Weber-Lewerenz, B., 2021. Corporate digital responsibility (CDR) in construction engineering—Ethical guidelines for the application of digital transformation and artificial intelligence (AI) in user practice. Springer Nature SN Applied Sciences. 3(10). doi: 10.1007/s42452-021-04776-1.

[35] Kiron, D., Kruschwitz, N., Reeves, M., 2013. The benefits of sustainability-driven innovation. MIT Sloan Management Review. 54(2).

[36] Schumacher, T., 2013. Lehrbuch der Ethik in der sozialen Arbeit (German) [Working Book for Ethics in social work]. Beltz Juventa Publishing: Germany.

[37] Danaher, J., Saetra, H., 2022. Technology and moral change: The transformation of truth and trust. Ethics and Information Technology. 24(35). doi: 10.1007/s10676-022-09661-y.

[38] Königs, P., 2022. Artificial intelligence and responsibility gaps: What is the problem? Ethics and Information Technology. 24(36). doi: 10.1007/s10676-022-09643-0.

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EDITORIAL

Thermal Characteristics of Structural Lightweight Concrete

Yeong Huei Lee[1*], Yee Yong Lee[2], Shi Yee Wong[3]

[1] *Department of Civil and Construction Engineering, Faculty of Engineering and Science, Curtin University Malaysia, CDT250, Miri, Sarawak, 98009, Malaysia*

[2] *Department of Civil Engineering, Faculty of Engineering, Universities Malaysia Sarawak, Jalan Datuk Mohammad Musa, Kota Samarahan, Sarawak, 94300, Malaysia*

[3] *School of Built Environment, University of Technology Sarawak, No. 1, Jalan Universiti, Sibu, Sarawak, 96000, Malaysia*

A higher cooling load is required with an increasing room temperature that resulted from the high thermal conductivity and low time lag of conventional construction materials [1]. Such a high cooling load increases the carbon footprint from the energy consumption during building performance. The condition can be worsened with the urban heat island phenomenon, as the cooling load prolongs to night time for maintaining indoor thermal comfort. Hence, structural lightweight concrete (SLC) serves as an alternative in concrete structures for reducing the carbon footprint during building performance. Countries with tropical climates have the highest amount of energy consumption for cooling loads. SLC may significantly reduce the cooling loads within the structures' service life. The indoor environment is sealed from outside weathering with building form in achieving human thermal comfort. Apart from roofing, the wall is the major component in building form with predominant exposure to heat transfer. Heat transfer mechanism through conduction, convection and radiation increases indoor temperature and requires higher energy for reducing the temperature. Roofing and wall components contented higher areas for heat transfer mechanism. A lightweight concrete block and SLC comprising load-bearing members and a non-bearing wall is a sustainable solution for the concrete construction industry.

The outdoor wall experiences different temperature patterns throughout the day as a result of varying thermal loads, such as solar radiation and infrared exchange between the wall and its surroundings that

*CORRESPONDING AUTHOR:
Yeong Huei Lee, Department of Civil and Construction Engineering, Faculty of Engineering and Science, Curtin University Malaysia, CDT250, Miri, Sarawak, 98009, Malaysia; Email: yhlee@civil.my

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retains thermal capacity. Heat waves transmit from the external wall surface to the internal ends, which increases the room temperature and thence decreases occupants' comfort. While in transition, the intensity of the heat wave dwindles as it penetrates the inner surfaces of building walls, causing a delay in the transfer of heat. The reduction in the intensity of heat waves is referred to as the decrement factor, while the delay in the transfer of heat at an appropriate time is termed time lag. Assessing these parameters offers a means of gauging the level of thermal comfort provided by the building envelope, prompting an investigation into the energy-saving potential of the materials used in the building.

Thermal properties include specific heat capacity, thermal conductivity, thermal diffusivity, decrement factor and time lag that affect materials' thermal performance. Specific heat capacity shows the material's heat storage through the decision on the amount of required energy for increasing the material's temperature by 1 Kelvin or degree Celsius in a unit mass. Materials with high specific heat capacity assist building envelopes' performance in achieving a higher level of thermal comfort through the indication of consistent room temperature without the influence of fluctuating outdoor temperatures. Thermal conductivity refers to the heat conductivity's inclination of a material in a motionless state. As such, room comfort is achievable through the usage of low-thermal conductivity materials for ideal thermal performance. Thermal diffusivity accounts for a material's thermal conductivity and specific heat capacity. Room comfort within a building envelope is undeniably warranted through low thermal diffusivity material with high specific heat capacity and low thermal conductivity.

While investigating the dynamic thermal characteristics of concrete materials, time lag and decrement factor are the two indicators of energy consumption prediction for building performance. In the study of Lee et al. [2], SLC may reduce a significant amount of energy for the cooling load if compared to the normal concrete, with other parameters remaining constant. The research has enhanced sustainable features with the introduction of agro-industrial waste of palm oil shells into a lightweight concrete matrix. The dynamic thermal characteristics of construction materials acquired professionals' attention, for the potential optimization of the thermal performances of a building envelope.

In response to the superior characteristics of thermal performance, concrete strength needs to be studied for a higher-performance application. As the air voids are the heat insulation layer in the concrete matrix, the voids also adversely affect the concrete strength. Traditionally, lightweight concrete gains lower concrete strength [3], with the same proportion of cement, aggregate and water, compared to conventional concrete. However, with reference to the ACI specifications of structural concrete, a 24%-28% density reduction resulted in 40%-50% energy savings, compared to conventional concrete, in accordance with the energy analysis from Lee et al. [2]. A balance is required for satisfying both design specifications of structural strength and thermal insulating properties.

In a brief, low specific heat and conductivity are specifically desirable in the tropics' construction industry. Specific thermal performance characteristics (i.e. high time lag and a low decrement factor) are essential for slow heat transfer from the outdoors to indoors within a longer time period through low heat dispersion [4].

Conflict of Interest

There is no conflict of interest.

References

[1] Stewart, I.D., Oke, T.R., Bechtel, B., et al., 2015. Generating WUDAPT's Specific Scale—Dependent Urban Modeling and Activity Parameters: Collection of Level 1 and Level 2 Data [Internet]. ICUC9, Toulouse, France (20-24 July) 5(4), 1-4. Available from: http://www.meteo.fr/icuc9/LongAbstracts/gd2-3-6861222_a.pdf

[2] Lee, Y.H., Chua, N., Amran, M., et al., 2021.

Thermal performance of structural lightweight concrete composites for potential energy saving. Crystals. 11, 461.
DOI: https://doi.org/ 10.3390/cryst11050461

[3] Tan, W.L., Lee, Y.H., Tan, C.S., et al., 2022. Mechanical properties and fracture prediction of concretes containing oil palm shell and expanded clay for full replacement of conventional aggregates. Jurnal Teknologi. 84(2), 171-181.
DOI: https://doi.org/10.11113/jurnalteknologi.v84.17485

[4] Lee, Y.H., Amran, M., Lee, Y.Y., et al., 2021. Thermal behavior and energy efficiency of modified concretes in the tropical climate: A systemic review. Sustainability. 13, 11957.
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SHORT COMMUNICATION

Geometric Study of Two-Dimension Stellated Reentrant Auxetic Structures to Transformable Architecture

Mª Dolores Álvarez Elipe

Facultad de Artes y Humanidades, URJC, Madrid, 28032, Spain

ABSTRACT

Transformable architecture is totally linked to the study and knowledge of geometry. There are some materials in nature, whose geometric invariants establish equivalent structural behavior regarding the scalar transformations, developing different spatial typologies according to dimensional variation. Auxetic materials are characterized by their negative Poisson's ratio. They can change their geometric configuration from a line to a surface, and from a surface to a volume or spatial framework. This paper is based on establishing and comparing those stellated reentrant auxetic geometries to be able to build new spaces defined by their capacity for architectural transformation, studying analytically geometric properties of stellated reentrant auxetic structures that, from the molecular to the macroscopic level, can be part of the architecture construction. In this investigation, a comparative study by means of CAD of stellated reentrant auxetic patterns has been realized. A Computer-Aided Design study of stellated reentrant auxetic structures will be realized to use them in architecture. The geometric behavior of the different stellated reentrant auxetic patterns is analyzed from the developed study to generate a systematic comparison, evaluating properties of these forms, such as their maximum achievable area reductions in relation to the total length of bars of the structure, in order to obtain a growth factor.

Keywords: Transformable; Architecture; Geometry; Auxetic; Stellated; Reentrant; CAD; Growth factor

1. Introduction

When a material is stretched in one direction, it normally loses section in the perpendicular direction. The Poisson ratio, $\nu = -\, d\varepsilon_{trans}/d\varepsilon_{axial}$, ε_{trans} and ε_{axial}, can express mathematically the change of dimensions. They are the cause of axial and transversal elongations or contractions when the material contracts

*CORRESPONDING AUTHOR:
Mª Dolores Álvarez Elipe, Estética y Teoría de las Artes, URJC, Madrid, 28032, Spain; Email: mdolores_500@hotmail.com

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or expands in the perpendicular way. Colloquially speaking, v_{ij} is the Poisson ratio that expresses an elongation in the 'j' axe when a flattening is applied in the 'i' axe. Classical structures conserve their volume because they have a positive Poisson's ratio. If a structure thickens in all directions when pulled it and the same structure narrows when compressed it, it is an auxetic structure. A negative Poisson's ratio (NPR) is the characteristic of these types of structures [1-4]. It has been studied the auxetic properties of artificial materials (Gore-Tex®, foams, polymeric foams) and natural materials (skins, some minerals ...), developing molecular auxetic patterns to obtain auxetic structures [5].

Novel manufacturers have been designed by the utilization of auxetic patterns. Minimally invasive implantable devices, morphological structures of the forms and smart expandable actuators are the main areas of application [6]. Devices utilized for the development of drop-down satellite antennas like shape memory auxetics alloys (SMA) also exist [7]. They are based on auxetic patterns and they are utilized as intelligent actuators. Several post-processing steps were initiated in some research on the behavior of polyurethane foams with shape memory and auxetic properties [8]. The characteristics of some auxetic patterns of a new development of expandable stents in the field of medical appliances have been tested [9]. But, at the moment, the utility of these materials and their geometric behavior in the architecture size are unknown. Auxetic patterns can generate new models with novel transformable geometries. They will produce useful properties in order to generate novel deployable geometries by designing tasks. These geometries will be used for the development of novel transformable architectures.

Novel manufactures have been designed by the utilization of auxetic patterns. Minimally invasive implantable devices, morphological structures of the forms and smart expandable actuators are the main areas of application [6]. Devices utilized for the developing of drop-down satellite antennas like shape memory auxetics alloys (SMA) also exist [7]. They are based on auxetic patterns and they are utilized as intelligent actuators. Several post-processing steps were initiated in some researches on the behavior of polyurethane foams with shape memory and auxetic properties [8]. The characteristics of some auxetic patterns of new development of expandable stents in the field of medical appliances have been tested [9]. But, at the moment, the utility of these materials and their geometric behavior in the architecture size are unknown. Auxetic patterns can generate new models with novel transformable geometries. They will produce useful properties in order to generate novel deployable geometries by designing tasks. These geometries will be used to the development of novel transformable architectures.

Some auxetic and potentially auxetic patterns, normally classified as "reentrant" [10], "chiral" and "rotating" have been described in anterior investigations and researches. Sometimes, at the molecular level only a scheme of the pliability process of auxetic patterns is presented. This study occurs when the structure is submitted to uniaxial efforts and it is not enough [11]. Information at the architectural scale is only provided for rigid knots in the re-entrant hexatruss structures. So, it is important to study about other attributes of some auxetic geometries, realizing a comparative and systematic analysis. It would be interesting to generate novel deployable structures applicable in architecture [12].

In this research a comparison of CAD separate and 2D geometries of stellated reentrant auxetic patterns is shown. The methodology of the realized research pay attention on develop some stellated reentrant auxetic patterns by means of CAD of three unity geometries and three 2D models, from the knowledge acquires in anterior investigations [13], patents [14-16] and conferences [12,13], and own researches.

The nature patterns and the models that have been generated by other authors in sizes different to architecture have rigid knots. The present research works with the behavior when these patterns have articulated knots. The research is a theoretical investigation applicable to understand the aptitude of pliability in structures suitable for architecture. The results are theoretical too, and materials are not taken into account.

When the Computer Aided Design approach is developed, the geometrical qualities of some stellated reentrant auxetic patterns were tested and compared, focusing on the particular behaviors of those patterns apt for the development of transformable structures for architecture [17]. A growth factor will be obtained from the maximum area reductions of the structures (the relation between the additions of the total length of all the bars of the structure and their areas).

This research is the only investigation of comparison of stellated reentrant auxetic patterns in architecture done so far. A lot of patterns could be verified changing the dimension of the length of each bar of the separate structure. So, the geometric studies on these patterns could be infinite. The comparison of geometric changes for the same structure will not be realized. A comparison between regular unity patterns and regular 2D patterns will be carried out.

The research is supported by geometrical basic criteria.

2. Methodology and objectives

According to Yanping Liu & Hong Hu [4], auxetic structures are classified in different groups depending on its geometric configurations: Reentrant structures, chirals, rigid or semi-rigid rotating units, laminated angular layers, microporous polymers and crystalline liquid polymers. For architectonic structural elements usage, the proposed ones are: Reentrant, chirals, rotating units and microporous polymers.

In this article, the stellated reentrant structure, in its different variations, has been modeled in CAD software, firstly as individual pattern, in order to combine with itself and check the geometrical pliability conditions according to the chosen group configurations. The auxetic existing models with rigid knots have been studied. These auxetic models with rigid knots have been drawn in the CAD software like articulated structures that can be deployed. The work by flexion of the bars of existing models of two dimension stellated reentrant auxetic structures is transformed in a simple work of traction and compression. These patterns include the repetition of the unity pattern in order to form a planar structure (**Figure 1**). Depending on the repeated geometry this lattice will generate forms that can grow of quadrangular or circular form.

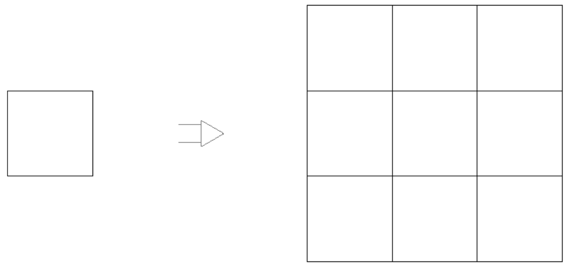


Figure 1. Generation of 2D pattern from the unity pattern, own elaboration.

The target is checking in a geometrical form the structural behavior of these geometries through the developed of a CAD library. The characteristics of some stellated reentrant auxetic patterns will be tested and a systematic comparison will be established. It will be connected the singular characteristics of those patterns useful to the development of transformable structures applies in architecture. A growth factor will be obtained from the maximum area reductions of the structures (the relation between the additions of the total length of all the bars of the structure and their areas).

3. Geometric study of stellated reentrant auxetic structures

The stellated reentrant auxetic structures have been developed with the computer-aided design program. These structures have been drawn in different positions to understand their geometrical behavior. As stated by Darcy Thomson [18] in his book “The growth of form”, all our form concepts must be linked to magnitude and direction. The reason is that the object’s shape can only be defined by the knowledge of its magnitude, real or relative, in some directions; and growth implies the same concepts of magnitude and direction, in relation to one more dimensional concept: Time.

In similar geometries the surface increases with the square, and the volume with the cube, of the linear dimensions. Having calculated that a small wading bird, the stilt, weighed 120 g. and that its legs measured 20 cm, it was supposed that a flamingo, which weighs more than 2 kg, should have legs 3 m long, to keep the same proportion. But it is obvious that, with the weights of both birds in the proportion of 1:15, the legs length (or any other linear dimension) will vary as the cube root of these numbers, approximately to the proportion 1:2.5. And according to this scale, the flamingo's legs should be as they really are, about 50 cm in length.

Although length growth and volume growth (which are usually equivalent to mass or weight) are parts of the same phenomenon or process, growth in the first case is remarkable. For example, a fish doubling its length multiplies its weight by at least eight; to double its weight, it is enough to go from 10 cm to 12 cm in length. Secondly, the correlation between length and weight in some animals is understood. In other words, determining the value of k in the formula W = kL3, allows us to relate one magnitude to the other at any time.

The scaling effect does not depend on itself. It depends on its relationship with its entire environment. One of the most common scaling effects is caused by some physical efforts acting directly on the surface of a body.

There is a principle of dynamic similarity whereby the "dimensions" remain the same in equilibrium equations, but the relative values are altered with the scale. Numerous architectural projects have been based on principles of nature [19].

Possible positions in space of some auxetic stellated reentrant patterns have been developed from they are fully folded until their maximum opening is achieved, achieving a variation of their surface or volume with the same mass. The target is to know the opening and closing conditions of the angles generated in nodes, to determine if these turns are superficial or spatial and in which directions they are generated according to the geometric conditions of the imposed structure.

The relationship between the amounts of material used and the surface obtained is also analyzed, by the 2 dimensions structure analysis. For this purpose, the total length of all bars used in the design of each pattern will be counted, as an analogy to the quantity of material. To know these amounts of material in mass units, specific sections of bars and specific materials should be defined. In this research, the aim is to find a general theoretical behavior, so the length identifies perfectly those linear elements utilized. A relationship (K) between the area (A) and the length (L) will be given, in order to understand the growth values of these special structures. The surface of each pattern will correspond to the square, circumference or polygon (as appropriate) where the figure is registered. From the division and subtraction of K_{max} and K_{min}, growth factors FC (:) and FC (-) of each structure will be obtained.

Individually applicable patterns and their possible combinations are developed to generate structural developments based on size, as well as transform architectures that follow new geometric developments into deployable auxetic architectures. The auxetic models that will be studied geometrically will be the stellated reentrant auxetic structures. These stellated reentrant auxetic models can be generated from polygons (regular or irregular) by dividing their faces in two and folding those inwards (outward behavior is not auxetic).

The geometric variations on these patterns have no end. It could be verified a lot of behaviors by changing the dimension of each bar of the individual pattern that affects the whole group. However, the structures will be studied for totally regular patterns, with the aim of carrying out a comparative study between all of them where it can be visualized how the shape affects the growth capacity of the structure in an auxetic way.

4. Developed auxetic patterns and their foldability

4.1 Unity pattern

The behavior of different unity patterns of auxetic stellated reentrant auxetic structures is analyzed as a function of their geometric parameters. To generate these structures, the number of vertices that attack the central core in the individual pattern has been varied, achieving different properties. In this way, 3, 4 and 6-point individual stellated reentrant auxetic structures have been considered, in such a way that the behaviors of **Figures 2, 3 and 4** can be appreciated:

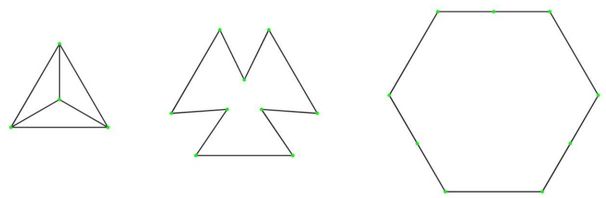


Figure 2. Unity of stellated reentrant structure of three points, own elaboration.

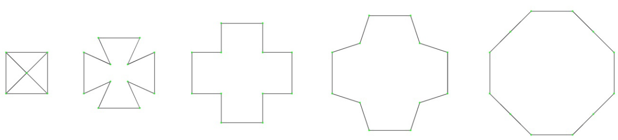


Figure 3. Unity of stellated reentrant structure of four points, own elaboration.

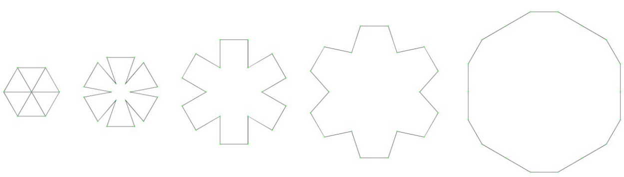


Figure 4. Unity of stellated reentrant structure of six points, own elaboration.

4.2 2D pattern

The behavior of different 2D patterns of auxetic stellated reentrant auxetic structures is analyzed as a function of their geometric parameters. To generate these structures, the repetition of the unity pattern in order to form a planar structure has been established, achieving different properties. In this way, 3, 4 and 6-point individual stellated reentrant auxetic structures have been considered, in such a way that the behaviors of **Figures 5, 6 and 7** can be appreciated:

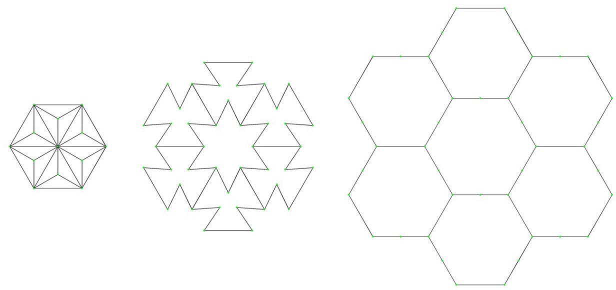


Figure 5. Set of stellated reentrant structure of three points, own elaboration.

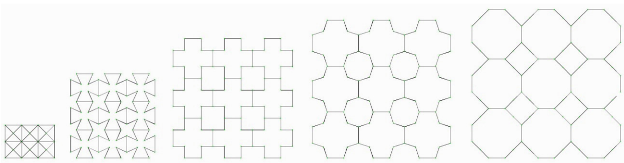


Figure 6. Set of stellated reentrant structure of four points, own elaboration.

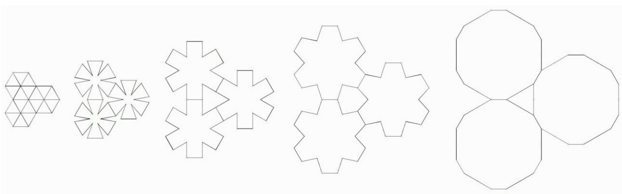


Figure 7. Set of stellated reentrant structure of six points, own elaboration.

5. Discussion of results

5.1 Unity pattern

The growth factor of each unit of the three structures analyzed has been graphically analyzed in **Figure 8**; reaching that growth is proportional to the number of sides as the conclusion. The bigger the number of sides, the more the structure grows when it is unfolded. And it looks like exponential growth.

The growth factors of these three stellated reentrant auxetic structures analyzed have also been analyzed numerically. The numerical data obtained, in relation to the growth of these structures and their mass-volume ratio, have been the following:

The growth factors, numerically, also increase with the number of vertices that attack the central core of the star. They obtain the highest growth factors for the individual 6-pointed stellated reentrant auxetic structures, which corroborates the graphic analysis.

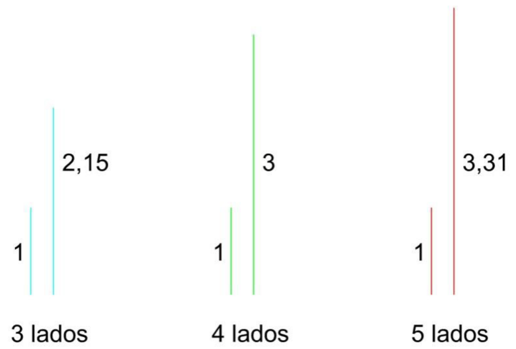


Figure 8. Growth factor of stellated reentrant auxetic structures, own elaboration.

Table 1. Relation between minimum areas (A_{min}) and maximum areas (A_{max}) with the total length of the bars of the structure, own elaboration.

	L	A_{min}	A_{max}	K_{min}	K_{max}	FC (:)	FC (-)
3 points	7.46	0.43	3.01	0.06	0.40	7.00	0.35
4 points	9.66	1.00	7.00	0.10	0.72	7.00	0.62
6 points	18.00	2.60	24.99	0.14	1.39	9.61	1.24

Analyzing these figures, it can also be observed that all their nodes are articulated in the plane, and two bars converge in them, allowing rotations in the xy axis that go from 0º to 90º or from 0º to 120º depending on the bar for the 3 points star, from 0º to 90º or from 0º to 135º depending on the bar for the 4-pointed star and from 0º to 90º or from 0º to 150º depending on the bar for the 6-pointed star. That is, with a bigger number of vertices that attack the central core, the maximum openings between the bars are increased.

5.2 2D pattern

As can be seen in **Figure 9**, as for the unit pattern, the bigger the number of sides in the generated star is, the more this structure grows when it is unfolded; that fact increases the growth factor in the joint structure. Therefore, it can be established that the joint structure grows proportionally with the sides of the polygon that generates it.

The growth factors of these three 2D stellated reentrant auxetic structures analyzed have also been numerically analyzed. The numerical data obtained in relation to the growth of the structures and their mass-volume ratio, have been the following:

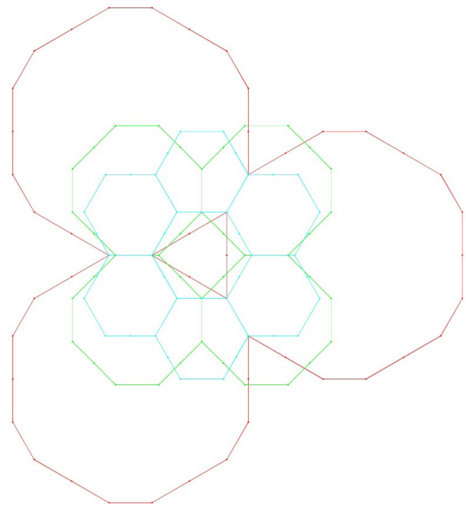


Figure 9. Overlap of the stellated reentrant auxetic structures of three, four and six points, own elaboration.

Table 2. Relation between minimum areas (A_{min}) and maximum areas (A_{max}) with the total length of the bars of the structure, own elaboration.

	L	A_{min}	A_{max}	K_{min}	K_{max}	FC (:)	FC (-)
3 points	32.78	2.6	21.53	0.08	0.66	8.28	0.58
4 points	74.91	9.00	80.89	0.12	1.08	8.99	0.96
6 points	114.00	21.99	233.03	0.19	2.04	10.60	1.85

The growth factors also increase with the number of vertices that attack the central core of the star, numerically; obtaining the highest growth factors the 6-pointed stellated 2D set reentrant auxetic structure, which corroborates the graphic analysis.

Analyzing these combinations of 2D star reentrant structures, it can also be observed that all their nodes are articulated in the plane, and two or three bars converge in them, allowing rotations in the xy axis ranging from 0º to 90º (2 bars) or from 0º to 120º (3 bars, unless it belongs to the outer perimeter of the set) for the 3-pointed star, from 0º to 90º (2 bars) or from 0º to 135º (3 bars, unless it belongs to the outer perimeter of the set), for the 4-pointed star and from 0º to 90º (2 bars) or from 0º to 150º (3 bars, unless it belongs to the outer perimeter of the set) for the 6-pointed star. That is, individual pattern properties are preserved for stellated reentrant auxetic structures.

6. Conclusions

It is concluded that planar stellated reentrant auxetic structures have useful growth factors to apply to surfaces of architecture. The maximum openings between the bars are increased with the number of bars. They never fully collapse auxetically. It can be a problem to transport them. The stabilization concept should be developed at a certain opening moment [20,21]. The next step will be developing the opening and closing points of the mechanisms that would have to be stabilized to convert them into architectural structures.

7. Limitations

This is a theoretical study of the geometry of the two-dimension-stellated reentrant auxetic structures to transformable architecture. But architecture is linked to the use of materials. So, these results are limited by this fact. To use these results, the total length of all bars used in the design of each pattern (L) will be changed to the real quantity of material (mass). This way, the lightness of the deployable structure will be obtained.

This type of pattern is very useful to transformable architecture, and they generate advantages to the transport and posterior deployment of the structure. They are useful to install as quick assembly structures.

Conflict of Interest

There is no conflict of interest.

References

[1] Lakes, R.S., 1987. Foam structures with a negative Poisson's ratio. Science. 235, 1038-1040.

[2] Evans, K.E., 1991. Auxetic polymers: A new range of materials. Endeavour. 15, 170-174.

[3] He, C., Liu, P., McMullan, P.J., et al., 2005. Toward molecular auxetics: Main chain liquid crystalline polymers consisting of laterally attached para-quaterphenyls. Physica Status Solidi. 242, 576-584.

[4] Liu, Y., Hu, H., 2010. A review on auxetic structures and polymeric materials. Scientific Research & Essays. 5, 1052-1063.

[5] Griffin, A.C., Kumar, S., Mc Mullan, P.J., 2005. Textile Fibers Engineered from Molecular Auxetic Polymers [Internet]. National Textile Center Research Briefs-Materials Competency. 1-2. Available from: https://citeseerx.ist.psu.edu/document?repid=rep1&type=pdf&doi=cb33e93d733dbe578bb48b914d837bb0595ba5e6

[6] Álvarez, M.D., 2019. Tensioned auxetic structures manual calculus. Journal of Architectural Environment & Structural Engineering. 2(1), 23-31.

[7] Scarpa, F., Jacobs, S., Coconnier, C., et al., 2010. Auxetic shape memory alloy cellular structures for deployable satellite antennas: Design, manufacture and testing. EPJ Web of Conferences. 6, 27001.

[8] Bianchi, M., Scarpa, F., Smith, C.W., 2010. Shape memory behaviour in auxetic foams: Mechanical properties. Acta Mater. 58, 858-865.

[9] Tan, T.W., Douglas, G.R., Bond, T., et al., 2011. Compliance and longitudinal strain of cardiovascular stents: Influence of cell geometry. Journal of Medical Devices. 5, 041002.

[10] Friis, E.A., Lakes, R.S., Park, J.B., 1988. Negative Poisson's ratio polymeric and metallic foams. Journal of Materials Science. 23, 4406-4414.

[11] Álvarez, J.C., Díaz, A., 2012. Comparative study of auxetic geometries by means of computer-aided design and engineering. Smart Materials and Structures. 21(105004), 1-12.

[12] Álvarez, M.D., Anaya, J., 2018. Development of reentrant hexatruss structures to apply to architecture. Journal of Construction. 17(2), 209-214.

[13] Álvarez, M.D., 2020. A comparative study of the pliability of separate auxetic architectonic structures by means of CAD. Advances in Sciences and Engineering. 12(1), 41-46.

[14] Anaya, J., Álvarez, M.D. (inventors), 2018. Estructura reticular transformable. Spanish Patent. ES 2,659,841, A1.

[15] Anaya, J., Álvarez, M.D., Serrano, R. (inventors), 2018. Barra regulable mediante sistema de presión para estructuras reticulares. Spanish Patent. ES 1,259,645 U; U 202032627 (2). 2018 Apr 21.

[16] Anaya, J., Álvarez, M.D., Serrano, R. (inventors), 2018. Sistema de unión para estructuras reticulares móviles. Spanish Patent. ES 1,238,524 Y; U 201931716 (8). 2019 Nov 12.

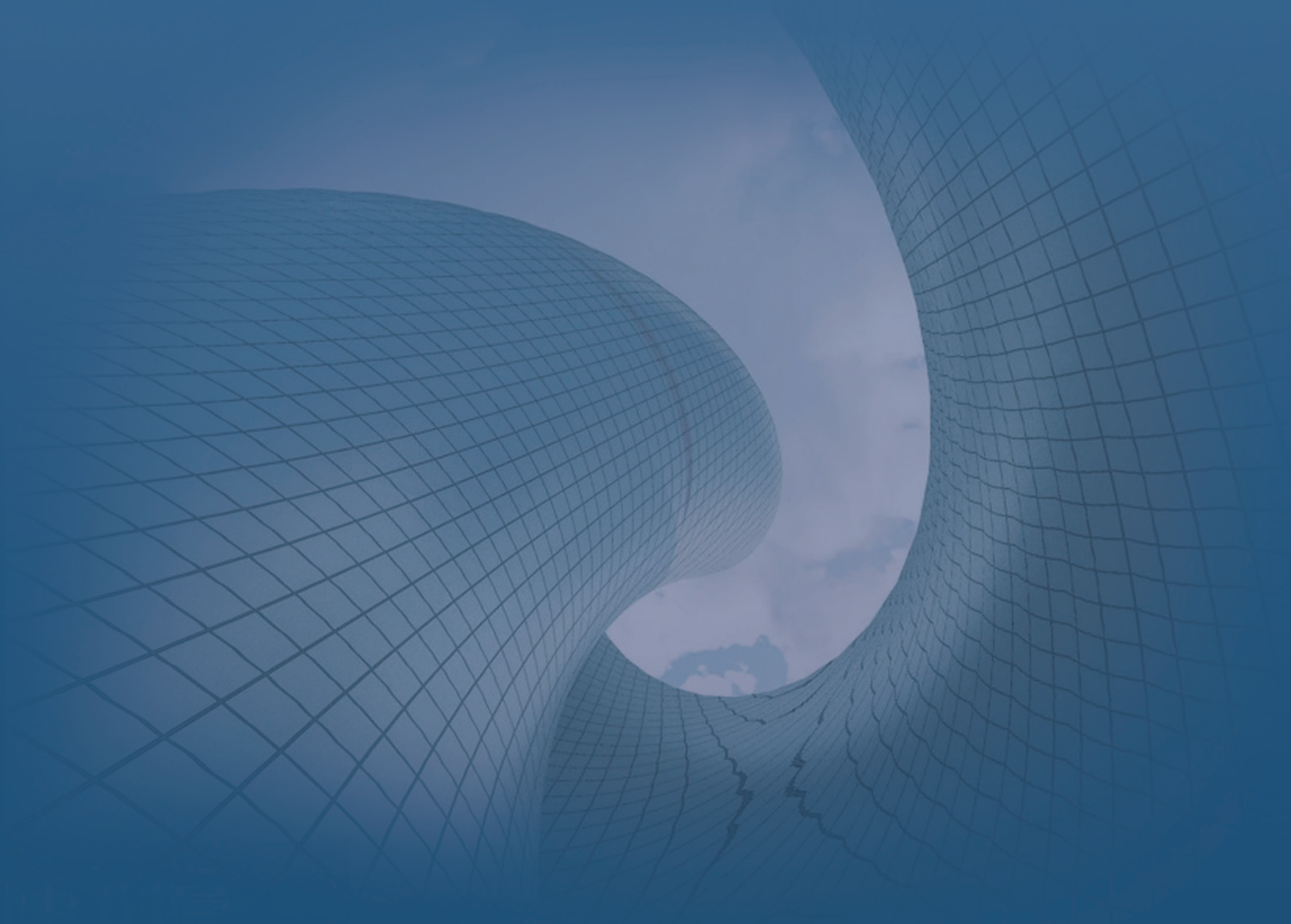
[17] Álvarez, M.D., 2019. Transformable geometries of architecture between the years of 1950 and 2015. Journal of Architectural Environment & Structural Engineering Research. 2(2), 6-17.

[18] Thompson, D., 2003. Sobre el crecimiento y la forma. Cambridge University Press: UK.

[19] Álvarez, M.D., Anaya, J., 2018. Review of contemporary architecture projects based on nature geometries. Revista de la construcción. 17(2), 215-221.

[20] Álvarez, M.D., 2020. Tensegrities and tensioned structures. Journal of Architectural Environment & Structural Engineering Research. 3(3), 10-16.

[21] Álvarez, M.D., 2022. Knot types used by transformable and rigid linear structural systems. Journal of Architectural Environment & Structural Engineering Research. 5(2), 1-15.



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