

DuSTcube: A Stereotomic 3D-printed Housing Unit meant for Mediterranean Areas

The aim of this paper is to present the project of a modern Mediterranean house, meant especially for “reconstruction” – therefore conceived for places hit by environmental disasters or by war – and designed according to sustainability criteria. The project consists of a minimal housing module inspired by vaulted structures typical of traditional Mediterranean architecture and it is designed to merge the construction principles of stereotomy with modern digital fabrication technologies. The module measures 25 square meters and it comprehends all the essential services of a house, but it can be replicated in space to form more complex urban agglomerations. The unit is designed to be composed of stereotomic ashlar made of 3D-printed stone and it can be assembled without the use of centrings thanks to the conical profile of the internal vaults. The use of 3D printing allows to customise the blocks in terms of shape and porosity, without producing waste: this way the various components can be optimised according to their static behaviour, to their weight or to insulation criteria. It is possible to keep the construction process green by using recycled material, such as waste stone powder or debris from the demolition or destruction of existing buildings.

Keywords: *Architectural design, stereotomy, sustainable architecture, Mediterranean architecture, digital fabrication, 3D-printing*

Introduction

Nowadays, the AEC (Architecture, Engineering and Construction) field has been characterised by a large amount of research focused on sustainability. As a matter of fact, it is estimated that 37% of the global emissions come from the construction industry¹ and that the most used materials, such as concrete, steel and aluminium, have a great carbon footprint².

According to the objectives of the European Green Deal³, it is important to consider the necessity to change our way of building, using green materials, trying to recycle industrial waste as the main resource and finding new strategies to keep the built structures sustainable in the long term.

The focus of this paper is the Mediterranean basin, for which a new paradigm of a stereotomic Mediterranean House has been proposed. This housing model has been developed for contexts hit by war or environmental disasters, and, therefore, it has been conceived for long-term “reconstruction”. The name DuSTcube explains

1. European Commission. *Building and construction*. Available at: https://single-market-economy.ec.europa.eu/industry/sustainability/buildings-and-construction_en. [Accessed 5 June 2025.]

2. UN environment programme. *Building Materials And The Climate: Constructing A New Future*. Available at: [https://www.unep.org/resources/report/building-materials-and-climate-constructing-new-future#:~:text=The%20buildings%20and%20construction%20sector,have%20a%20significant%20carbon%20footprint](https://www.unep.org/resources/report/building-materials-and-climate-constructing-new-future#:~:text=The%20buildings%20and%20construction%20sector,have%20a%20significant%20carbon%20footprint.). [Accessed 5 June 2025.]

3. European Commission. *The European Green Deal*. Available at: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en. [Accessed 5 June 2025.]

1 the essence of the project, which appears as a cubic volume with arched openings
2 and that has been thought to be fabricated using the 3D printing of dust (stone
3 powder, desert sand, etc.).

4 In the Mediterranean area there are several examples of places in need of
5 reconstruction operations. In Syria, for example, a ten-years conflict has caused the
6 destruction of cities and heritage, and the population has been forced to move from
7 their homes to new places. This phenomenon has caused social pressure and tension
8 that local governments were unable to mitigate also because of limited financial
9 possibilities⁴.

10 Italy, on the contrary, has witnessed some natural disasters due to climate
11 change: floodings, landslides and earthquakes are dangerously growing, and so is
12 the urge not only to contain their effects but also to find fast and cheap solutions for
13 those people whose houses are damaged or even destroyed. The flood that hit Emilia
14 Romagna in May 2023 became the third most expensive natural disaster of the
15 world in 2023⁵.

16 Moreover, the latest years were characterized by an increasing of migratory
17 fluxes. For example, 123.000 immigrants arrived in Europe in 2021, and this
18 phenomenon has been encouraged by the conflict between Russia and Ukraine,
19 from which more than 1 million people escaped looking for shelter⁶.

20 In a world afflicted by conflicts and disasters, DuSTcube is a “vision” for long-
21 term reconstruction in the Mediterranean area. It represents an architectural
22 synthesis of innovation, sustainability and cultural heritage that helps reaffirm the
23 role of the Mediterranean identity in shaping the future of resilient and responsible
24 design.

25 26 27 **Literary Review**

28
29 The optimal development of this project has required a focus on a series of
30 themes such as current architectural solutions for shelters and emergency dwellings,
31 the Mediterranean vernacular architecture, and the stereotomic discipline. The
32 literature review has helped face the design phase with more awareness.

4. UN-Habitat (2021) *Restoration of cultural heritage and urban identity in Syria*. Urban Recovery Framework.

5. SKY TG24. *Cambiamento climatico in Italia, i disastri naturali hanno causato 35 miliardi di danni*. Available at: <https://tg24.sky.it/ambiente/2023/10/20/cambiamento-climatico-italia-danni-costo>. [Accessed 5 June 2025.]

6. Bruno R, Bevilacqua P, Rollo A, Barreca F, Arcuri N (2022) A Novel Bio-Architectural Temporary Housing Designed for the Mediterranean Area: Theoretical and Experimental Analysis. *Energies* 15(9).

1 *Building in Post-Disaster Contexts*

2

3 In post-disaster contexts, it is necessary to categorise the different types of
4 dwelling solutions: they can be distinguished into emergency shelters, transitional
5 shelters and transitional housing.

6 Emergency shelters are usually meant to immediately host the victims of a
7 disaster and to be used for a very short period after the disaster, sometimes only a
8 few hours.

9 Temporary shelters are meant to continue to provide essential goods and to host
10 people for a relatively short time. Emergency and temporary sheltering can be
11 distinguished especially for behaviour matters: for example, in temporary sheltering
12 cases it is important to understand where and how the victims will be fed, while in
13 emergency sheltering cases this does not happen because the stay will be too short.
14 Temporary housing is meant to host people for a period that can vary between six
15 months and a few years and, for this reason, it consists of more “robust” structures
16 that allow people to run all the activities of everyday life^{7,8}.

17 Currently, existing temporary housing solutions are often inadequate because
18 they are conceived by designers or technicians who are not familiar with the context,
19 and who, consequently, neglect the real needs and the identity of the population⁹.
20 Moreover, they often are not sustainable because of the use of materials with a high
21 embodied carbon, as concrete and steel, and because of a lack of attention towards
22 the recyclability and the reuse of the components¹⁰.

23 For example, the Gümüşpınar Temporary Settlement realised after the 1999
24 earthquake in Turkey, has been built using mainly prefabricated components made
25 of a blend of cement, wood shaving chipboard and zinc-aluminium. This solution
26 makes this housing system not environmentally friendly, due especially to the lack
27 of awareness about the theme of sustainability in 1999. Moreover, the housing
28 solution did not consider the local identity and needs¹¹.

29 A more virtuous example is represented by the “Superadobe” developed by
30 Nader Khalili in 1984 (Figure 1). It consists of a domed structure realised by piling
31 up layers of bags full of raw earth and dirt, which helps obtain thick walls able to
32 resist bad weather conditions and natural calamities (e.g. floods or earthquakes). The
33 Superadobe is a very sustainable system since it is realised with local materials and
34 can be assembled by the population itself after a training period¹². Despite the

7. Quarantelli E. L. (1995) Patterns of sheltering and housing in US disasters. *Disaster Prevention and Management* vol. 4(3): 43-53.

8. Lines R, Faure Walker JP, Yore R (2022) Progression through emergency and temporary shelter, transitional housing and permanent housing: A longitudinal case study from the 2018 Lombok earthquake, Indonesia. *International Journal of Disaster Risk Reduction* 75.

9. Félix D, Feio A, Branco J M (2013) Guidelines to Improve Sustainability and Cultural Integration of Temporary Housing Units. In *Proceedings of the 6th International i-Rec Conference. Sustainable Post-Disaster Reconstruction: From Recovery to Risk Reduction* (Ascona, Switzerland, 26-30 May 2013).

10. Montalbano G, Santi G (2023) Sustainability of Temporary Housing in Post-Disaster Scenarios: A Requirement-Based Design Strategy. *Buildings* 13(12).

11. Ibid.

12. Abulnour A H (2014) The post-disaster temporary dwelling: Fundamentals of provision, design and construction. *HBRC Journal* 10: 10-24.

1 sustainability and the easy construction process, the assembly of a Superadobe
 2 requires a considerable number of people and physical strength to be completed¹³.
 3 Moreover, this kind of solution puts some limitations from the geometric point of
 4 view.

5



6

7 **Figure 1.** A superadobe structure built in Djibouti (Africa) by Andrew Caya

8 Source: Photos by Andrew Caya, taken from [www.dvidshub.net/image/591295/new-eco-dome-](http://www.dvidshub.net/image/591295/new-eco-dome-signals-changes-local-village)
 9 [signals-changes-local-village](http://www.dvidshub.net/image/591295/new-eco-dome-signals-changes-local-village).

10

11 Nowadays large-scale 3D printing is becoming an alternative for the realisation
 12 of housing modules. A good example is represented by the houses built in Nacajuca
 13 (Mexico) by the company ICON together with the non-profit organisation New
 14 Story. These houses, meant for people in extreme poverty conditions, are composed
 15 of 3D printed monolithic walls and a wooden roof. The houses have been designed
 16 with the feedback of the locals in order to meet their needs; moreover, since
 17 Nacajuca is in a seismic zone, the structures have been conceived according to safety
 18 requirements¹⁴. The material used for the 3D printed part was a special concrete
 19 developed by the American company, and this goes against the principle of using
 20 local and sustainable materials. Moreover, this kind of large-scale additive
 21 manufacturing, which works through the extrusion of the fluid mortar, requires very
 22 heavy machinery, which implies a big initial financial investment.

23

24

13. Kamal R, Rahman M S (2018) A study on feasibility of super adobe technology –an energy efficient building system using natural resources in Bangladesh. *IOP Conference Series: Earth and Environmental Science* 143.

14. Baguess B (2019) ICON + New Story + ECHALE Unveil First Homes in 3D-Printed Community. *ICON website*: <https://www.iconbuild.com/newsroom/icon-new-story-echale-unveil-first-homes-in-3d-printed-community>. [Accessed 7 June 2025.]

1 *The Vernacular Architecture as a Source of Inspiration*

2

3 As previously said, the main purpose of this project is to create a model of
4 architecture meant for post-disaster housing with specific attention to the
5 architectural identity of the Mediterranean basin and to sustainability.

6 Mediterranean vernacular architecture has been built mainly with stone, and it
7 is characterised by massive structures often covered with vaults or pseudo-vaults,
8 with a few openings which sometimes have an arched profile (Figure 2).

9



10

11 **Figure 2.** *Some Mediterranean vernacular structures: a) trulli in Cisternino*
12 *(Apulia, Italy); b) the Old city of Mardin (Turkey); c) a traditional dammuso from*
13 *Pantelleria (Sicily, Italy)*

14 *Source: a) photo by José Jovena; b) photo by Osman Karagöz; c) iStock.*

15

16 These historical structures are also known to have a good performance from a
17 sustainability point of view.

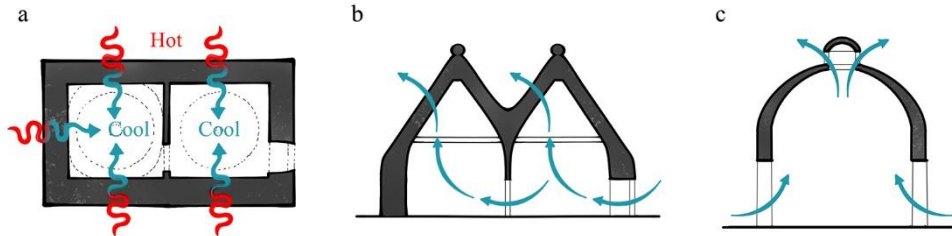
18 A study conducted by the University of Miho, focused on the city of Nablus in
19 Palestine, has shown that the old city centre has a better performance than the new
20 one. As a matter of fact, some graphs show that the energy requirement for heating
21 and cooling artificial systems is lower for traditional buildings than for new ones.
22 Moreover, a lower carbon footprint has been estimated for the traditional
23 construction materials considered, among which stone is mentioned, rather than for
24 new ones¹⁵.

25 Vernacular Mediterranean architecture often presents a series of passive
26 cooling strategies favoured by the material used and by the formal configuration.
27 First of all, the high thermal inertia of stone guarantees a slow heat exchange
28 between the interior and the exterior (Figure 3a).

29 Stack effect is another fundamental strategy that guarantees passive cooling. In
30 Apulian *trulli* warm air can flow out through cracks in the pseudo-vault, thus
31 sucking up fresh air. Cooling was favoured also by the presence of a water tank

15. Al Tawayha F, Braganca L, Mateus R (2019) Contribution of the Vernacular Architecture to the Sustainability: A Comparative Study between the Contemporary Areas and the Old Quarter of a Mediterranean City. *Sustainability* 11(3): 896.

1 underneath the structure¹⁶ (Figure 3b). The same effect is obtained in vaults that
 2 present an opening on the ceiling, like the *Kolah farangi* in the Iranian architectural
 3 tradition. A *Kolah farangi* is a hole on the vaulted ceiling meant to work both as a
 4 natural light catcher and as a means for natural ventilation¹⁷ (Figure 3c).
 5



6
 7 **Figure 3.** Schemes of some passive cooling strategies in vernacular Mediterranean
 8 architecture: a) the effects of high thermal inertia of stone in a trullo; b) stack effect
 9 in a trullo; c) stack effect in an Iranian *Kolah farangi*

10 Source: schemes by the authors.

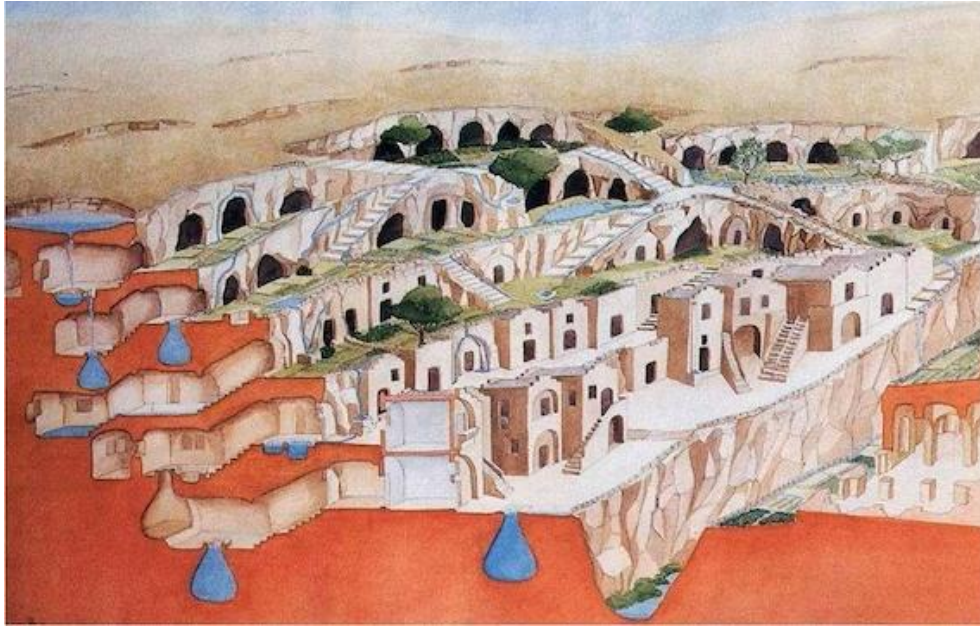
11
 12 Sustainability is also strictly linked to the theme of water management,
 13 especially in the Mediterranean area, where water scarcity is increasing because of
 14 climate change. This is happening especially in the Southern and Eastern
 15 Mediterranean countries¹⁸. Sometimes systems for water collection and reuse have
 16 been developed since antiquity: a good example is the complex system of cisterns
 17 realised in the city of Matera, where water is not abundant¹⁹ (Figure 4).
 18

16. Stigliano M (2012) Towards a sustainable design project. In G Fallacara (ed), 188-209, *Stereotomy. Stone architecture and new research*. Paris: Presses des Ponts.

17. Zarandi M M (2006) Natural ventilation as a solution towards sustainability in architecture. In *Proceedings of the International Workshop on Energy Performance and Environmental Quality of Buildings* (Milos, Greece, 6-7 July 2006).

18. Ferragina E (2010) The water issue in the Mediterranean. In M Scoullou, E Ferragina (eds), 53-79. *Environmental and Sustainable Development in the Mediterranean*. Barcelona: European Institute of the Mediterranean.

19. Grano MC (2020) Palombari, cisterne e pozzi per l'approvvigionamento idrico nei Sassi di Matera (Basilicata) [Palombari, cisterns and wells for water collection in the sassi of Matera (Basilicata)].



1
2 **Figure 4.** A scheme of the water collection in the *Sassi* of Matera.

3 *Source: Drawing by Debora Giorgi.*

4
5 Some of these sustainability strategies have been considered for the
6 development of the project of DuSTcube.

7
8 *Stereotomy: a Construction Discipline Born in the Mediterranean Area*

9
10 In the design process of DuSTcube, the principles of stereotomy have been
11 considered and applied.

12 Stereotomy is an ancient discipline also known as “the art of cutting solids”,
13 which was used in the past to design and realise masonry vaults. This discipline was
14 based on the application of the rules of projective geometry to design vaulted spaces
15 discretised optimally, considering both static and aesthetic matters²⁰.

16 Stereotomic systems are historically associated with the use of stone and are
17 meant to produce mainly compressive stresses and to work even without mortar or
18 reinforcements.

19 An architecture must respect three invariants to be considered stereotomic:

- 20
21 1. Prefigurative invariant: the overall geometry of the vaulted space must be
22 determined, and its configuration must be clear.
23 2. Technical-geometric invariant: every single constructive element (ashlar)
24 must be geometrically defined, and it must be represented in order to be
25 correctly produced.

20. Fallacara G, Gadaleta R (2019) Stereotomy: Architecture and Mathematics. In B Sriraman (ed) *Handbook of the Mathematics of the Arts and Sciences*. Cham: Springer.

1 3. Static invariant: the equilibrium of the structure must be guaranteed²¹.

2 Many Mediterranean vernacular architectures, as the ones discussed in the
3 previous paragraph, present vaulted spaces, but not all of them can be considered
4 stereotomic. For example, a *trullo* is not a stereotomic structure, since its roof is built
5 using juxtaposed irregular rocks, which create a so-called pseudo-vault instead of a
6 vault (the technical-geometric invariant and the static invariant are not respected).
7 Also vaults made of bricks cannot be considered stereotomic because they are
8 composed of standardised elements instead of ashlar optimised specifically for the
9 structure (the technical-geometric invariant is not respected).

10 Even if stereotomy has reached its theoretical and practical peak in France in
11 the 16th-17th century, there are examples of stereotomic architectures since the
12 Hellenistic period in a wide geographical area whose centre is the Mediterranean
13 Basin²². Stereotomic vaults are part of the Mamluk architectural heritage (various
14 of them, for example, are placed in the Cairo Fatimid Walls²³) and are also present
15 in many historical buildings of southern Italy, Spain, etc.

16 Therefore, stereotomy can be considered part of the Mediterranean identity, and
17 designing a housing module through an innovation of this discipline would not only
18 take into account sustainability and ecological matters, but also cultural ones.

19 Using stereotomy can help obtain very effective structures and reduce the need
20 for metal reinforcements – since stereotomic structures work mainly under
21 compression loads – and this can help keep the construction process greener.
22 However, it is a very complex discipline that requires a specific know-how, and
23 nowadays it is explored mainly in universities research institutes to obtain
24 experimental pavilions and temporary structures designed using form-finding
25 algorithms, parametric modelling software and realised using digital fabrication
26 technologies.

27 Some examples are the *Armadillo Vault*, realised by the Block Research Group
28 of the ETH Zürich for the International Architecture Exhibition organised by La
29 Biennale di Venezia in 2016²⁴ (Figure 5a), *Stone Matters* realised by AAU Anastas
30 Architects in Jericho in 2017²⁵ (Figure 5b), the *Hypar Vault* (Figure 5c) and the *Flux*
31 *Vault* (Figure 5d), both realised by Giuseppe Fallacara with the New Fundamentals
32 Research Group in 2017²⁶. There are also some recent examples of 3D printed

21. Fallacara G (2007) *Towards a stereotomic design. Notions of stereotomy, digital stereotomy and topological transformations: reasoning about the construction of the form*. Rome: ARACNE Editrice.

22. Galletti S (2017) Stereotomy and the Mediterranean: Notes Toward an Architectural History. *Mediterranean International Journal on the Transfer of Knowledge* 2: 73-120.

23. Salcedo-Galera M, Garcia-Bano R (2022) Stonecutting and Early Stereotomy in the Fatimid Walls of Cairo. *Nexus Network Journal* 24: 657-672.

24. Rippmann M, Van Mele T, Popescu M, Augustynowicz E, Echenagucia T, Barentin C, Frick U, Block P (2016) The Armadillo Vault. Computational Design and Digital Fabrication of a Freeform Stone Shell. In Adriaenssens S; Gramazio F; Kohler M; Menges A; Pauly M (eds) *Proceedings of the Conference Advances in Architectural Geometry 2016* (Zurich, Switzerland, 9-13 September 2016), 344-363.

25. ArchDaily (2017) *Stone Matters/AAU ANASTAS*. Available at: www.archdaily.com/870512/stone-matters-aau-anastas.

26. Fallacara G, Barberio M (2018) An Unfinished Manifesto for Stereotomy 2.0. *Nexus Network Journal* 20: 519-543.

1 stereotomic shells, such as the *Striatus Bridge*, realised by Zaha Hadid Architects
 2 and the Block Research Group in 2020 in Venice²⁷ (Figure 5e) and *Hexastone*,
 3 designed by Michael Hermann and Benjamin Spaeth and fabricated by the company
 4 Vertico²⁸ (Figure 5f).
 5



6
 7 **Figure 5.** Examples of experimental stereotomic contemporary structure: a) the
 8 *Armadillo Vault* realised by the Block Reserch Group of the ETH Zurich in Venice
 9 (Italy) in 2016; b) the pavilion *Stone Matters* realised by AAU Anastas Architects in
 10 Jericho (Palestine) in 2017; c) the *Hypar Vault* realised by Giuseppe Fallacara and
 11 the *New Fundamentals Research Group* in Saint-Savine (France) in 2017; d) the
 12 *Flux Vault* realised by Giuseppe Fallacara and Maurizio Barberio in 2017 and
 13 exposed at the fair *Salon Rocalia* (France); e) the *Striatus Bridge* realised by Zaha

27. Bhooshan S, Bhooshan V, Dell’Endice A, Chu J, Singer P, Megens J, Van Mele T, Block P (2022) The Striatus bridge. Computational design and robotic fabrication of an unreinforced, 3D-concrete-printed masonry arch bridge. *Architecture, Structure and Construction* 2: 521-543.

28. ParametricArchitecture Editorial Team (2023) *Hexastone combines traditional architecture with 3D concrete printing technology*. Available at: www.parametric-architecture.com/hexastone-combines-traditional-architecture-with-3d-concrete-printing-technology/?srsltid=AfmBOooK_o2xgK-JFx-CBokSNK8JtJ2ERwiZagBamUPF0CbHUs2aD_hU [Accessed 6 June 2025.]

1 *Hadid Architects and the Block Research Group in 2020; f) Hexastone, realised by*
 2 *Michael Hermann and Benjamin Spaeth together with Vertico*
 3 *Source: a) www.armadillovault.com/armadillo-vault, photo by David Escobedo of The Escobedo*
 4 *Group; b) [www.domusweb.it/it/architettura/2019/01/02/la-pietra-conta-larchitettura-di-elias-e-](http://www.domusweb.it/it/architettura/2019/01/02/la-pietra-conta-larchitettura-di-elias-e-yousef-anastas.html)*
 5 *yousef-anastas.html; c) photo by Maurizio Barberio; d) photo by Gaz Blanco; e) photo by Naaro,*
 6 *www.zaha-hadid.com/design/striatus/; f) www.vertico.com/projects/hexastone.*

7
 8 There are also a few examples of effective contemporary architectures that have
 9 been designed and realised according to stereotomic principles.

10 The *Bureaux SNBR*, designed by Giuseppe Fallacara and completed in 2015, is
 11 an office building for the company SNBR, located in Saint-Savine, near Lyon
 12 (France). The structure is composed of four diaphragm stone arches that bear a gable
 13 roof. The arches have been conceived stereotomically and the static performance
 14 has been optimised through the use of S-shaped joints, that increase the friction
 15 among the ashlar²⁹ (Figure 6a).

16 The detail of the S-shaped joint has been reprised in another contemporary
 17 stereotomic architecture: the Saint-Dizier Market, realised in 2023 by studiolada. It
 18 is a parallelepiped structure with external walls made of self-bearing stone masonry.
 19 It is characterised by large arched openings with a variable catenary profile,
 20 conceived stereotomically. The largest ones present an S-shaped profile like the one
 21 adopted in the *Bureaux SNBR*³⁰ (Figure 6b).

22 A different example of stereotomy used in contemporary architecture is
 23 represented by the flat vault realised in 2018 by AAU Anastas Architects for the gift
 24 shop of the St Mary of the Resurrection Abbey in Jerusalem³¹ (Figure 6c). This flat
 25 vault is a clear reprise of the one patented by Joseph Abeille in 1699³².

29. Fallacara G (2015) *Vers une architecture en pierre. Bureaux SNBR à Troyes: 2008-2015* [Towards stone architecture. SNBR offices in Troyes: 2008-2015]. Paris: Presses des Ponts.

30. Cavaliere I, Valentini A (2025) *Collectif studiolada. Architettura credibili per il futuro in pietra* [Collectif studiada. Credible architectures for a lithic future]. Rome: Gangemi Editore International.

31. Hernández D (2018) The Flat Vault / AAU ANASTAS. *ArchDaily*. <https://www.archdaily.com/903127/the-flat-vault-aau-anastas>.

32. Miodragovic I V, Kotnik T (2016) Geometric Versatility of Abeille Vault. A Stereotomic Topological Interlocking Assembly. In A Hernejoja, T Österlund, P Markkanen (eds) *Complexity & Simplicity - Proceedings of the 34th International Conference on Education and Research in Computer Aided Architectural Design in Europe* (Oulu, Finland, 24-26 August 2016) 2: 391-397.



1
2 **Figure 6.** *Some examples of contemporary architectures in which stereotomy has*
3 *been used: a) the Bureaux SNBR by Giuseppe Fallacara; b) the Saint-Dizier Market*
4 *by studiolada; c) the gift shop of the St Mary of the Resurrection Abbey in Jerusalem,*
5 *designed and realised by AAU Anastas Architects*

6 *Source: a) photo by Gaz Blanco; b) www.studiolada.fr/projet/marche-couvert-saint-dizier; c) photo*
7 *by Mikaela Burstow, www.archdaily.com/903127/the-flat-vault-aau-anastas.*

8
9 The main problem with the realisation of stereotomic structures is the necessity
10 of custom centring, which have a great impact on costs, waste production and on
11 the assembly complexity. This aspect has been considered during the design process
12 of DuSTcube.

13 14 15 **Methodology: The Steps of the Design Process of DuSTcube**

16
17 The DuSTcube project was conceived as an intersection between
18 Mediterranean ancient construction tradition and needs on the one hand, and
19 contemporary design techniques on the other.

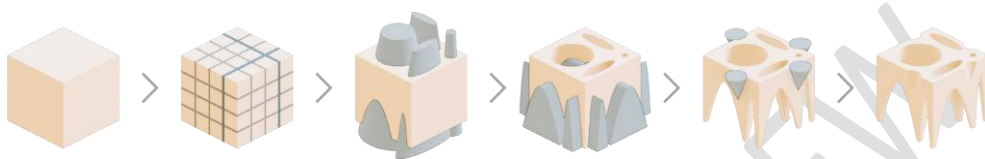
20 First of all, some considerations about the thermal performance requirements
21 were made. The Mediterranean Area is characterized by mild temperatures, that can
22 reach high peaks during summer. It is fundamental to find strategies that can help
23 reduce energy consumption linked to the use of artificial air conditioning systems.
24 As it was previously described, vernacular Mediterranean architecture is
25 characterised by models that can nowadays be of inspiration for sustainable
26 contemporary solutions. For example, the frequent use architectural vaults and thick
27 stone walls not only are aesthetic peculiarities but also means to stabilize internal
28 temperatures and optimize airflows. This kind of information helped make the next
29 steps: they became the operative rules through which reinterpret the housing
30 tradition using both stereotomic principles and contemporary technologies (in terms
31 of design and potential future construction).

32

1 *The Geometry of DuSTcube and the Application of Stereotomy Rules*

2
3 Stereotomy offered all the geometric rules to design self-supporting vaults with
4 minimal need of additional supports, allowing DuSTcube to be a modular housing
5 unit with a unique aesthetic – given by the particular shape of each ashlar – and the
6 possibility of being dry assembled with discrete blocks.

7 Parametric design tools were used to generate the vaulted geometry inside a
8 simple cube that was cut through catenary and conical geometries (Figure 7) and
9 then it was divided into blocks with customised shapes and optimized individual
10 performance.

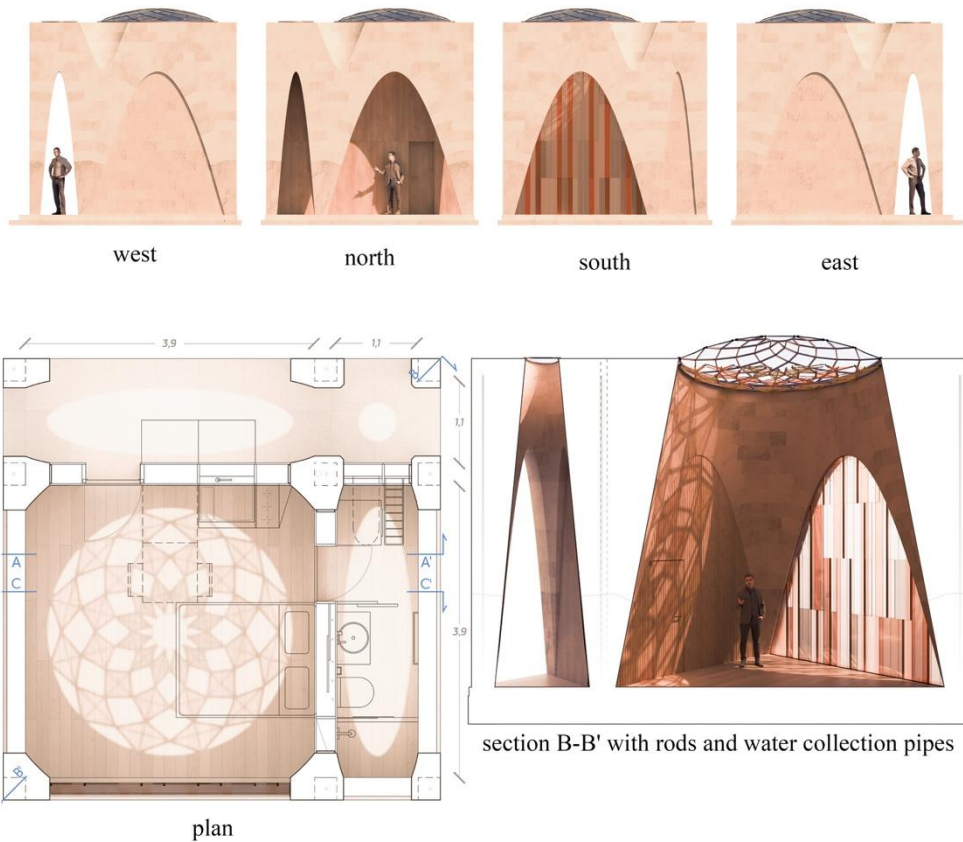


12
13 **Figure 7.** The geometric process through which DuSTcube has been designed.

14 *Source: drawings by the students Ester Faccilongo, Adriano Marra and Pierfrancesco Uva.*

15
16 These operations of subtraction and discretization were all part of a
17 stereotomical strategy aimed at designing an architectural project that did not need
18 centring to be built and that could potentially work under the action of gravity
19 alone. As a matter of fact, the conical profiles of the internal vaults allow the
20 structure to remain stable during the assembly process.

21 The subtractions mentioned above were made not only for aesthetical and
22 statical purposes, but they also followed a strict organization logic inspired by the
23 previous studies in order to distribute inside a 25-square-meter area sleeping,
24 hygienic and culinary functions, maintaining high standards of decency at the same
25 time.



1

2 **Figure 8.** *Technical drawings: the four façades, the planimetry and a cross section*
 3 *Source: drawings by the students Ester Faccilongo, Adriano Marra and Pierfrancesco Uva.*

4

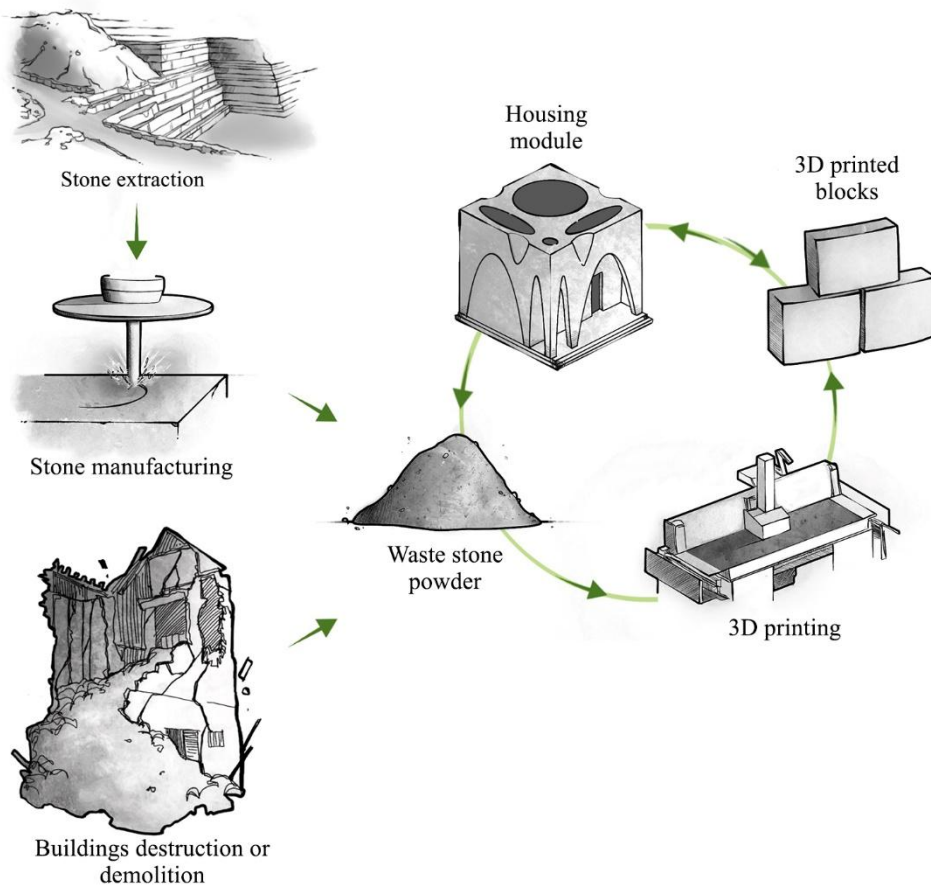
5 *Materials and Digital Fabrication*

6

7 The majority of vernacular Mediterranean architectures is built with stone,
 8 which is widely available in this geographical area. Since stone is characterised by
 9 a high thermal inertia, using it as a construction material helps create internal
 10 comfortable living conditions both in summer and in winter, without the use of
 11 insulant layers. However, a diffusion in the use of natural stone for construction
 12 would lead to an increasing in excavation due to the higher demand and this does
 13 not fit with the Green Deal’s objectives. For this reason, it was important to find a
 14 new way to work with stone, taking advantage of its properties but avoiding waste
 15 and excessive consumption, considering that in 2015 82,6 million tons of stone were
 16 produced, but the amount of waste was over 70% of the total³³. The solution was to
 17 work with recycled stone powder instead of traditional quarry blocks, obtaining it
 18 both from stone cutting industry leftovers and powders coming from collapsed

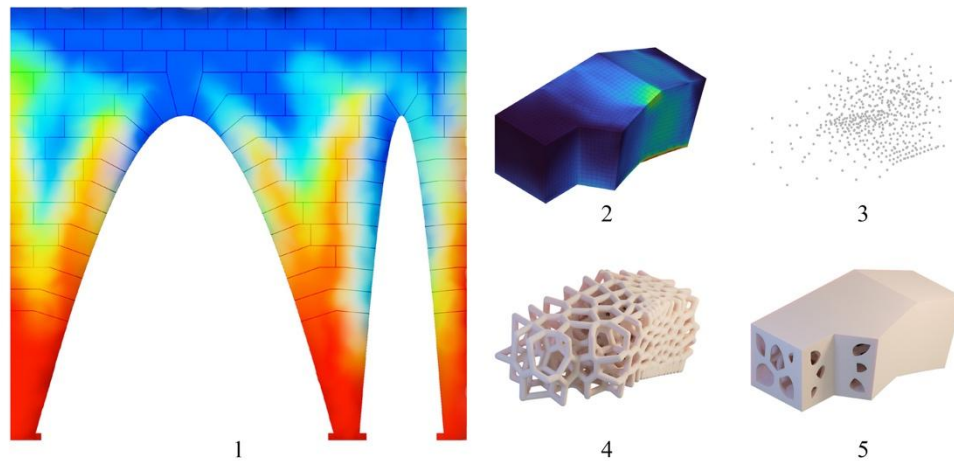
33. MICS – Made in Italy Circolare e Sostenibile. 2.04 STONE – *SusTainable ecOdesign reusiNg quarring wastE*. Available at: <https://www.mics.tech/projects/2-4-stone-sustainable-ecodesign-reusing-quarring-waste/>. [Last Accessed 7 June 2025.]

1 buildings. The 3D printed stone itself can be recycled in case of the dismantling of
 2 the housing unit, keeping the final product completely recyclable (Figure 9).



3
 4 **Figure 9.** *A scheme of the life cycle of stone*
 5 *Source: drawing by the author Dario Costantino.*

6
 7 The additive manufacturing technique selected to work with this powder is
 8 binder jetting, which allows the precise deposition of a binding agent over layers of
 9 stone dust, forming solid objects without the need of high temperatures or heavy
 10 moulds. Moreover, working with 3D printing technologies leads to several
 11 advantages such as a high level of customisation (keeping it possible to make
 12 variations of a dwelling or of its components without the necessity to produce a lot
 13 of formworks or moulds) and a low need of specialised human labour. 3D printing
 14 gives designers also the possibility of calibrating the porosity and density of each
 15 block optimising material usage according to stresses (Figure 10). Therefore, it is
 16 possible to adapt the location of the blocks within the building, placing the densest
 17 ones where stresses are higher.



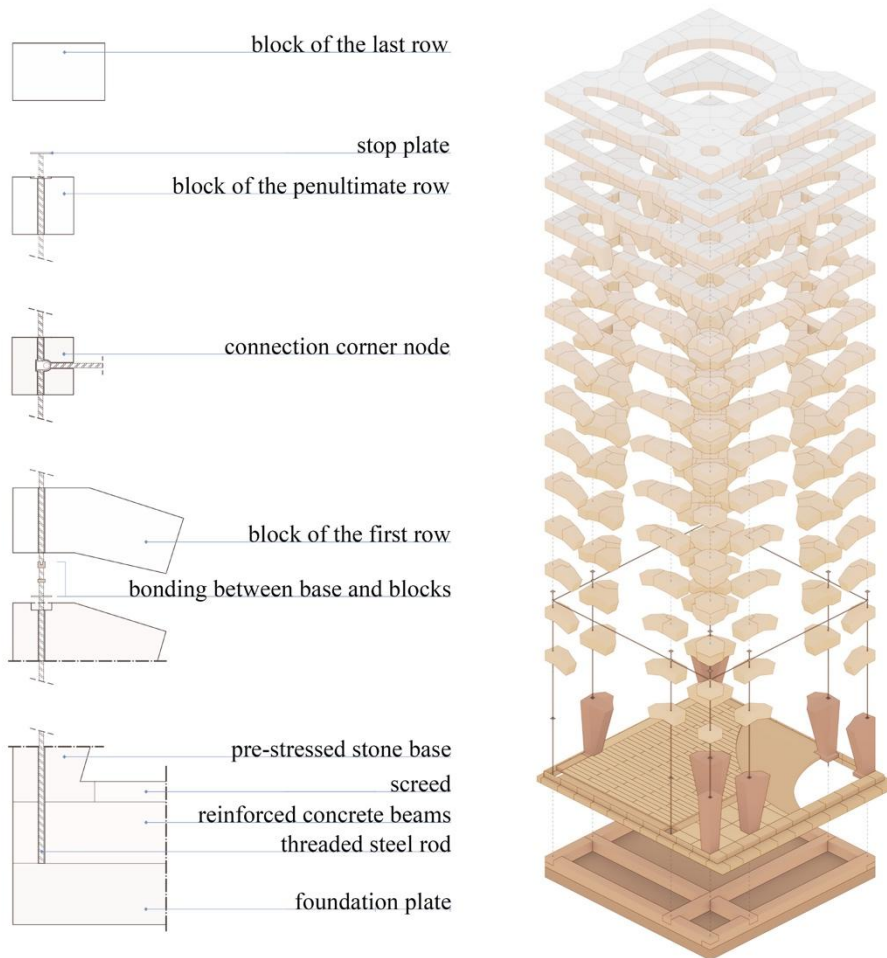
1
2 **Figure 10.** *A scheme of the variation of porosity of the stone ashlars according to*
3 *stresses. 1) The stresses of the entire structure are calculated through a finite*
4 *elements analysis; 2) the stresses inside each single ashlar are calculated; 3) the*
5 *volume of the ashlars is used as the domain for a point cloud whose density changes*
6 *according to the intensity of the stresses; 4) the points of the point cloud are*
7 *connected one another to form a lattice grid, which represents the filling of the*
8 *ashlars; 5) the faces of the ashlars are closed using surfaces*

9 *Source: drawings by the students Ester Faccilongo, Adriano Marra and Pierfrancesco Uva.*

10
11 For static and graphic simulations Lecce stone powder was used not only due
12 to its availability in the Apulia region but also due to its valid mechanical and
13 aesthetical properties in terms of feasibility, cohesion, resistance and surface quality.

14 *Assembly Process and Constructive Efficiency*

15
16
17 The construction of DuSTcube has been conceived to be as fast and
18 straightforward as possible, since it has been thought for difficult contexts where
19 skilled labour is limited and there is urgency. This is why stereotomy was extremely
20 useful, since blocks were designed to interlock and self-stabilize through geometry
21 alone. As a matter of fact, this housing unit can be built through a dry assembly
22 process that could be carried out mostly manually, customizing block in order not
23 to overcome problematic weights. Moreover, the absence of mechanical fasteners
24 or joints simplifies also a potential disassembly of the house for re-use or relocation
25 operations. Of course, for safety reasons a static stabilization system was designed
26 through the use of post-tensioned cables that start from the foundations and cross
27 the structure along its entire height (Figure 11).



1
2 **Figure 11.** A scheme of the subdivision into ashlar, in which the post-tension cables
3 are visible

4 *Source: drawings by the students Ester Faccilongo, Adriano Marra and Pierfrancesco Uva.*

5
6 The full assembly sequence begins with the preparation of a levelled ground
7 slab onto which the lower blocks are placed. As the block are printed directly in situ,
8 the vault gets built and each course is laid with slightly inclination adjustments that
9 follow the conical geometry, enabling the structure to stabilize incrementally. The
10 roofing elements are also 3D printed and are thought to integrate solar panels and
11 possibly ventilation chimneys.

12 This approach minimizes the need for logistics and industrial infrastructures,
13 giving the chance of prefabricate an entire unit, pack it and transport it or even build
14 it directly wherever it is needed.

15 Moreover this unit has been designed to be modular and so it is possible to
16 cluster multiple houses and form bigger collective environments suitable both for
17 reconstructed neighbourhoods and small scale settlements (Figure 12).



1
2
3
4

Figure 12. *Rendering of a settlement made of DuSTcube units*
Source: drawing by the students Ester Faccilongo, Adriano Marra and Pierfrancesco Uva.

5 Eventually also furniture has been considered part of the design process: all the
6 internal components were designed to be deployable and printable through wood
7 powder – chosen in order to give the interior a warm and cozy atmosphere. This
8 choice was linked to the necessity of customize the interiors and optimize the 25-
9 square-meter area (Figure 13).

10



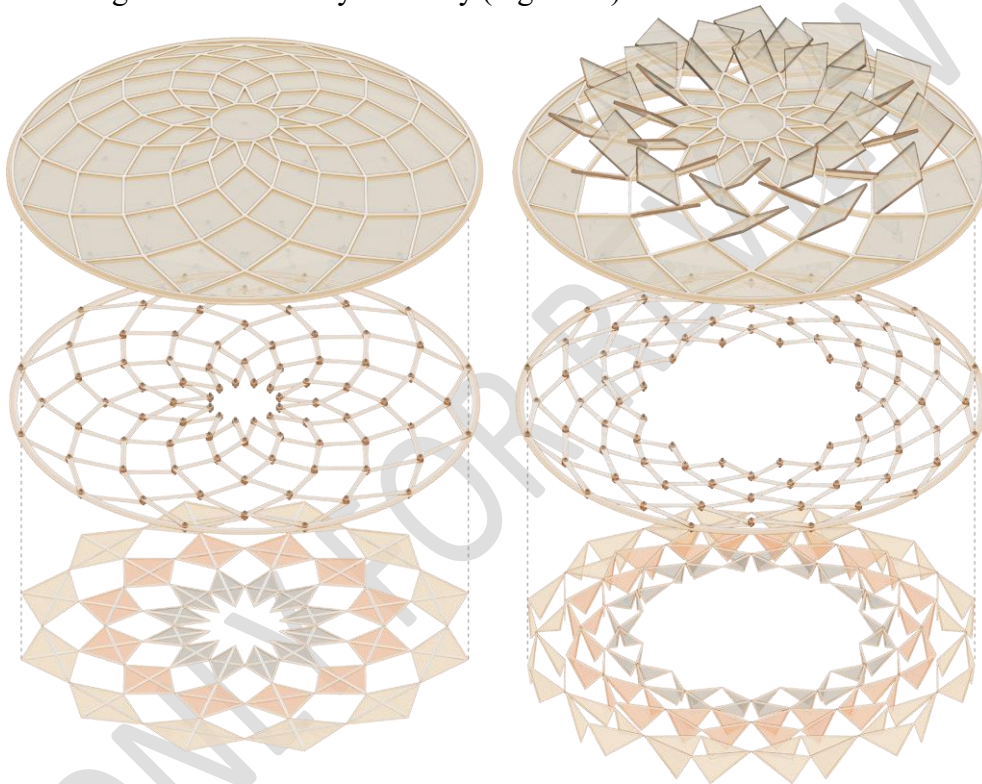
11
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13

Figure 13. *Rendering of a settlement made of DuSTcube units*
Source: drawing by the students Ester Faccilongo, Adriano Marra and Pierfrancesco Uva.

1 *Benefits of the Design Proposal and Sustainability Strategies*

2
3 From an environmental standpoint, the proposal tries to face all the
4 contemporary challenges of sustainability and green design, reducing embodied
5 energy, limiting construction waste and polluting materials like cement. Moreover,
6 its thermal inertia, given by the predominant use of stone-based compositions,
7 contributes to natural cooling in summer and heat containment in winter, reducing
8 energy consumes due to artificial conditioning systems.

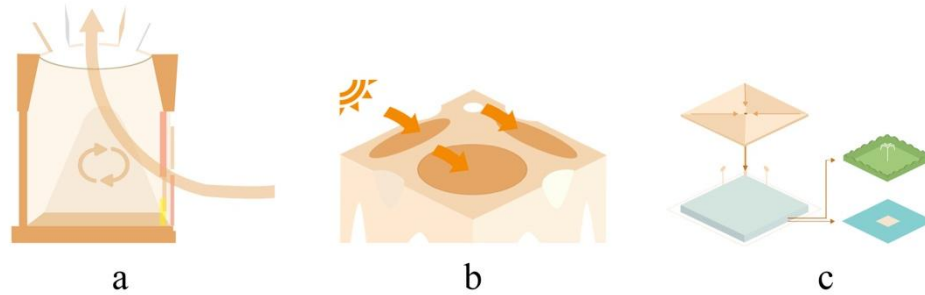
9 The entire upper portion of the central area is covered by a system of semi-
10 transparent photovoltaic glass windows connected to an automated engine. The idea
11 is that the layers of this element move in relation to the progression of the sunlight,
12 sheltering the inhabitants dynamically (Figure 14).



13
14 **Figure 14.** *Scheme of the functioning of the glass window that covers the central*
15 *space*

16 *Source: drawing by the students Ester Faccilongo, Adriano Marra and Pierfrancesco Uva.*

17
18 Furthermore, this opening on the roof allows passive ventilation strategies such
19 as the stack effect to favour the reduction of artificial cooling and heating systems
20 (Figure 15a). The glass is thought to be photovoltaic, in order to contribute to the
21 efficiency of the structure through the production of clean energy (Figure 15b).
22 Finally, the possibility of collecting rainwater was considered, therefore the roof has
23 a slight slope aimed at letting water flow towards a vertical pipe that bring it to an
24 underground tank (Figure 15c).
25



1
2 **Figure 15.** *Schemes of the sustainability strategies adopted: a) the stack effect; b)*
3 *energy production through photovoltaic glass; c) rainwater collection and reuse*
4 *Source: drawing by the students Ester Faccilongo, Adriano Marra and Pierfrancesco Uva.*

5
6 Besides technical aspects linked to sustainability strategies, it also has a layered
7 cultural value: on the one hand the combination of stereotomy, vaulted geometries
8 and local materials encourages an aesthetic and formal reconnection to the
9 Mediterranean tradition and also helps an architectural continuity – reconnecting
10 new houses with historical ones and with geographical specificities; on the other
11 hand the introduction of contemporary digital tools leads to new ways of thinking
12 about architecture and to more strategic applications of design, saving time, money
13 and workforce. The modularity and the digital reproducibility of the components
14 also makes the system scalable, adaptable and easily customisable according to
15 needs or cultural contexts. The system is also upgradeable, changing and evolving
16 through future advancements in materials and technologies.

17 18 19 **Discussion: Limitations and Challenges**

20
21 DuSTcube responds to a large spectrum of needs that arise in post-crisis
22 contexts, particularly in the Mediterranean basin. As a matter of fact, this project is
23 not only a shelter, but it is the result of a layered design reasoning that proposes
24 a new interpretation of the topics of contemporary construction and reconstruction:
25 architecture becomes not only a way to rebuild what is lost, but it is also a tool to
26 reconfigure a sense of place and identity.

27 However, despite its conceptual strength, DuSTcube is still a theoretical and
28 experimental project, whose prototypes have been made only in small scales (Figure
29 16).



Figure 16. *The two realised maquettes*

Source: photos by the students Ester Faccilongo, Adriano Marra and Pierfrancesco Uva.

Therefore, there are a lot of challenges that must be faced in order to make DuSTcube a real buildable project. As a matter of fact, the transition from small to large scale could strongly influence all the parameters taken into consideration and, furthermore, it is necessary consider factors as time and climatic agents, which could drastically alter the printed stone. Only a few individual components have been printed using Lecce stone powder, so mechanical tests under real environmental stressors such as humidity and UV are still pending. Moreover, the binder formulation needs to be refined in order to best balance aesthetic and performance.

Another important thing that must be considered is that stereotomic design processes and block production can be both complex and may require specific digital skills that may not be available especially in emergency context. To mitigate this, future developments should include the creation of open-source parametric tools and block libraries and preset codes that allow faster design operations.

A critical aspect is represented by the recourse to technologies that are still expensive and uncommon in the construction industry, like 3D printing and automated windows. The impact of this aspect would be mitigated only in case of massive diffusion of these technologies in the future.

Lastly, logistical uncertainties remain, since the coordination between design, production, transport and assembly require an operational framework that needs to be worked and refined, especially considering that both materials and techniques are still unconventional and in emergency contexts it is important to make a compromise that obviously leans more towards functionality and speed, even though DuSTcube is not a common emergency shelter but a strategic building designed to regenerate destroyed contexts and last.

Conclusions

The DuSTcube project proposes a radical yet grounded model for post-crisis architecture in the Mediterranean world. It blends ancient construction logics and

1 design techniques with new materials and digital technologies, proposing a modular
2 dwelling that collects principles of sustainability and hospitality.

3 Even if at the moment it is still theoretical, the project opens new avenues for
4 architectural research, creating links among different disciplines and tools such as
5 stereotomy and 3D printing. Its limitations are clear and often explicit, but they do
6 not discredit the concept, rather they underline the necessary work that must be done
7 in order to go from theoretical experimentation to real construction, integrating a
8 deeper work on materials validation, systems and lighting.

9 Eventually in a world increasingly affected by conflicts, migration, climate
10 disruption, DuSTcube represents a vision of continuity, regeneration and
11 architectural dignity.

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