



Fig. 8. Masonry compressive strength vs Compressive strength of mortar for mortar thickness to masonry unit thickness ratio 0.10 and masonry unit strength 10.00–70.00 by step 10.00 using the optimal ANN-LM 4–9–1 model.

6. Conclusions

A comprehensive experimental database of 611 data points, collected from 81 experimental campaigns, is developed in this study to formulate an optimal computational model predicting the compressive strength of masonry. Four parameters, namely, the compressive strength of the masonry unit, the compressive strength of the mortar, the masonry height to thickness ratio and the mortar thickness to masonry unit thickness ratio are considered as input in this database, while one output parameter, the compressive strength of masonry is used.

Back Propagation Neural Networks (BPNN) models are then developed and trained to predict the compressive strength of masonry using four different optimization algorithms, namely, the Levenberg-Marquardt algorithm, the Broyden–Fletcher–Goldfarb–Shanno algorithm, the Particle Swarm Optimization algorithm, and the Imperialist Competitive Algorithm (ICA). To identify the optimal computational scheme that can more effectively predict the compressive strength of masonry, combinations for architectures have been tested and ranked based on their performance, adopting different numbers of neurons per hidden layer and different transfer functions.

The investigation leads to an optimal ANN model, optimized using the Levenberg-Marquardt algorithm, consisting of a structure with 9 neurons in the hidden layer, and employing the Minmax normalization technique in the range [0.00–1.00]. The Radial Basis (RB) transfer function is used in the hidden layer, while the Log-sigmoid transfer function is utilized in the output layer of this optimal model.

The capacity of the optimal machine learning model of this study to predict the compressive strength of masonry is highlighted, by a comparison with available literature proposals. Within this comparison, all performance indices obtained from the proposed model are significantly improved in comparison with the literature findings.

Using the optimal developed model, the contribution of each input parameter on the prediction of the compressive strength of masonry is evaluated, by adopting the SHapley Additive exPlanations (SHAP) method. It is shown that the most important parameter affecting the compressive strength of masonry is the mortar thickness to masonry unit thickness ratio followed in order by the mortar compressive strength, the masonry height to thickness ratio and the parameter with the smallest influence, which is the masonry unit compressive strength. However, when the investigation differentiates between masonry compressive strength values above 15 MPa (strong) or below 15 MPa (weak), a different outcome is obtained. Thus, for weak masonry, the main parameter affecting compressive strength is the masonry height to thickness ratio, while for strong masonry, the primary parameter influencing compressive strength is the mortar compressive strength.

Finally, the optimal computational model is used to further investigate and evaluate the nature of the compressive strength of masonry. Based on this investigation it is concluded that the relationship between the compressive strength of the masonry wall/prism and the compressive strength of the masonry unit is nonlinear. It is also shown that for higher slenderness of the masonry walls, increasing the mortar strength has less or almost no influence on the masonry compressive strength.

The study can be extended by further enriching the developed database, covering potential input parameters areas with less dense representation, such as units and mortar with compressive strength higher than 20 MPa. Additionally, the dataset can be expanded with the inclusion of typologies such as stone masonries in greater numbers.

CRediT authorship contribution statement

Amin Mohebkah: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation. **Anastasio Drougkas:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation. **Gabriele Milani:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation. **Liborio Cavaleri:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation. **Antonio Formisano:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation. **Panagiotis G. Asteris:** Writing – review & editing, Writing – original draft, Supervision, Software, Methodology, Investigation, Conceptualization. **Georgios A. Drosopoulos:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation. **Paulo B. Lourenço:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation.

Supplementary material

The *Parameters of ANNs*, the *Top 20 ANN Architectures* and *Comparison with Semi-Empirical Models* are included as [supplementary material](#) to this paper.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.istruc.2025.109189](https://doi.org/10.1016/j.istruc.2025.109189).

Data Availability

Data will be made available on request.

References

- [1] AbdelRahman B, Galal K. Influence of pre-wetting, non-shrink grout, and scaling on the compressive strength of grouted concrete masonry prisms. *Constr Build Mater* 2020;241:117985.
- [2] ACI 530.1-02/ASCE 6-02/TMS 602-22, n.d. Specification for Masonry Structures, Reported by the Masonry Standards Joint Committee (MSJC).
- [3] Alavi AH, Gandomi AH. Energy-based numerical models for assessment of soil liquefaction. *Geosci Front* 2012;3(4):541–55.
- [4] Aliu AA, Ariff NRM, Ametefe DS, John D. Automatic classification and isolation of cracks on masonry surfaces using deep transfer learning and semantic segmentation. *J Build Rehabil* 2023;8:28. <https://doi.org/10.1007/s41024-023-00274-6>.
- [5] Alkayem NF, Shen L, Mayya A, Asteris PG, Ronghua F, Di Luzio G, Strauss A, Cao M. Prediction of concrete and FRC properties at high temperature using machine and deep learning: a review of recent advances and future perspectives. *J Build Eng* 2023;83:108369.
- [6] Andolfato RP, Camacho JS, Ramalho MA. Brazilian results on structural masonry concrete blocks. *MJ* 2007;104:33–9. <https://doi.org/10.14359/18492>.
- [7] Apostolopoulou M, Armaghani DJ, Bakolas A, Douvika MG, Moropoulou A, Asteris PG. Compressive strength of natural hydraulic lime mortars using soft computing techniques. *Procedia Struct Integr* 2019;17:914–23.
- [8] Armaghani DJ, Asteris PG. A comparative study of ANN and ANFIS models for the prediction of cement-based mortar materials compressive strength. *Neural Comput Appl* 2020;33:4501–32. <https://doi.org/10.1007/s00521-020-05244-4>.
- [9] AS Committee 3700-2018, Masonry structures. Australian Standard Association, Sydney;2018.
- [10] Asteris PG, Antoniou ST, Sophianopoulos DS, Chrysostomou CZ. Mathematical Macromodeling of Infilled Frames: State of the Art. *J Struct Eng* 2011;137: 1508–17. [https://doi.org/10.1061/\(ASCE\)ST.1943-541X.0000384](https://doi.org/10.1061/(ASCE)ST.1943-541X.0000384).
- [11] Asteris PG, Argyropoulos I, Cavaleri L, Rodrigues H, Varum H, Thomas J, Lourenço PB. Masonry Compressive Strength Prediction using Artificial Neural Networks. Presented at the International Conference on Transdisciplinary Multispectral Modeling and Cooperation for the Preservation of Cultural Heritage. Cham, Switzerland, Athens, Greece: Springer; 2018. p. 200–24.
- [12] Asteris PG, Lourenço PB, Hajihassani M, Adami C-EN, Lemonis ME, Skentou AD, Marques R, Nguyen H, Rodrigues H, Varum H. Soft computing-based models for the prediction of masonry compressive strength. *Eng Struct* 2021;248:113276. <https://doi.org/10.1016/j.engstruct.2021.113276>.
- [13] Asteris PG, Mokos VG. Concrete Compressive Strength using Artificial Neural Networks. *Neural Comput Appl* 2019. <https://doi.org/10.1007/s00521-019-04663-2>.
- [14] Asteris PG, Plevris V. Anisotropic masonry failure criterion using artificial neural networks. *Neural Comput Appl*. 2017;28:2207–29. <https://doi.org/10.1007/s00521-016-2181-3>.
- [15] ASTM C 1552-23, Practice for capping concrete masonry units, related units and masonry prisms for compression testing. West Conshohocken, USA; 2023.
- [16] ASTM C1314-22. Standard Test Method for Compressive Strength of Masonry Prisms. West Conshohocken, PA: ASTM International; 2022.
- [17] ASTM C270-24, Standard Specification for Mortar for Unit Masonry. USA; 2024.
- [18] ASTM E 122-17, Standard practice for calculating sample size to estimate, with specified precision, the average for a characteristic of a lot or process. West Conshohocken, USA; 2017.
- [19] Atashpaz-Gargari E, Lucas C. Imperialist competitive algorithm: An algorithm for optimization inspired by imperialistic competition. 2007 IEEE Congress on Evolutionary Computation, 2007. CEC; 2007. p. 4661–7. 4425083.
- [20] Bakhteri J, Sambasivam S. Mechanical behaviour of structural brick masonry: an experimental evaluation. *Proc 5th Asia - Pac Struct Eng Constr Conf, Malays* 2003:305–17.
- [21] Balasubramanian SR, Maheswari D, Cynthia A, Rao KB, Prasad MA, Goswami R, Sivakumar P. Experimental determination of statistical parameters associated with uniaxial compression behaviour of brick masonry. *Curr Sci* 2015;109(11): 2094–102.
- [22] Barbosa CS, Lourenço PB, Hanai JB. On the compressive strength prediction for concrete masonry prisms. *Mater Struct* 2010;43:331–44. <https://doi.org/10.1617/s11527-009-9492-0>.
- [23] Basha SH, Kaushik HB. Evaluation of nonlinear material properties of fly ash brick masonry under compression and shear. *J Mater Civ Eng* 2015;27:04014227. [https://doi.org/10.1061/\(ASCE\)MT.1943-5533.0001188](https://doi.org/10.1061/(ASCE)MT.1943-5533.0001188).
- [24] Bennett RM, Boyd KA, Flanagan RD. Compressive Properties of Structural Clay Tile Prisms. *J Struct Eng* 1997;123:920–6. [https://doi.org/10.1061/\(ASCE\)0733-9445\(1997\)123:7\(920\)](https://doi.org/10.1061/(ASCE)0733-9445(1997)123:7(920)).
- [25] Binda L, Fontana A, Frigerio G. Mechanical behaviour of brick masonries derived from unit and mortar characteristics. Presented at the 8th International Brick and Block Masonry Conference. Dublin Repub Irel 1988;1:205–16.
- [26] Boffill Y, Blanco H, Lombillo I, Villegas L. Assessment of historic brickwork under compression and comparison with available equations. *Constr Build Mater* 2019; 207:258–72. <https://doi.org/10.1016/j.conbuildmat.2019.02.083>.
- [27] Bosiljkov V. Experimental and numerical research on the influence of the modified mortars on the mechanical properties of the brick masonry, PhD Thesis. Slovenia: University of Ljubljana; 2000.
- [28] Brencich A, Gambarotta L. Mechanical response of solid clay brickwork under eccentric loading. Part I: Unreinforced masonry. *Mater Struct* 2005;38:257–66.
- [29] Bröcker O. Die auswertung von tragfähigkeitsversuchen an gemauerten wänden. *Betonstein-Zeitung*; 1963. p. 19–21.
- [30] Carvalho M.A.B., 2015. Development and validation of a constructive solution in BTC, Master Thesis, UniMinho (in Portuguese).
- [31] Cavaleri L, Barkhordari MS, Repapis CC, Armaghani DJ, Ulrikh DV, Asteris PG. Convolution-based ensemble learning algorithms to estimate the bond strength of the corroded reinforced concrete. *Constr Build Mater* 2022;359. <https://doi.org/10.1016/j.conbuildmat.2022.129504>.
- [32] Cavaleri L, Di Trapani F, Macaluso G, Papia M. Attendibilità dei modelli per la valutazione dei moduli elastici delle murature suggeriti dalle norme tecniche. *Ing sismica* 2012;29(1):38–59.
- [33] Cavaleri L, Di Trapani F. Cyclic response of masonry infilled RC frames: Experimental results and simplified modeling. *Soil Dyn Earthq Eng* 2014;65: 224–42.
- [34] Cavaleri L, Papia M, Macaluso G, Di Trapani F, Colajanni P. Definition of diagonal Poisson's ratio and elastic modulus for infill masonry walls. *Mater Struct* 2014;47 (1-2):239–62.
- [35] Cheema TS, Klinger RE. Compressive Strength of Concrete Masonry Prisms. *JP* 1986;83:88–97. <https://doi.org/10.14359/1752>.
- [36] Christy CF, Tensing D, Shanthi RM. Experimental study on axial compressive strength and elastic modulus of the clay and fly ash brick masonry. *J Civ Eng Constr Technol* 2013;4:134–41.
- [37] CTE, 2008. Spanish Technical Building Code.
- [38] Cuomo M, Badalà A. Problematiche metodologiche relative alla determinazione sperimentale delle proprietà meccaniche dei materiali murari e dei loro componenti. *La Prot Del Patrim Cult-Ja Quest Sismica* 1997:657–83.
- [39] Dais D, Bal IE, Smyrou E, Sarhosis V. Automatic crack classification and segmentation on masonry surfaces using convolutional neural networks and

- transfer learning. *Autom Constr* 2021;125:103606. <https://doi.org/10.1016/j.autcon.2021.103606>.
- [40] Dayaratnam P. *Brick and Reinforced Brick Structures*. Oxford & IBH; 1987.
- [41] Drosopoulos GA, Stavroulakis GE. *Nonlinear mechanics for composite heterogeneous structures*. Boca Raton London New York: CRC Press, Taylor & Francis Group; 2022.
- [42] Drougkas A, Roca P, Molins C. Compressive strength and elasticity of pure lime mortar masonry. *Mater Struct* 2016;49:983–99. <https://doi.org/10.1617/s11527-015-0553-2>.
- [43] Drysdale RG, Hamid AA. Behavior of Concrete Block Masonry Under Axial Compression. *JP* 1979;76:707–22. <https://doi.org/10.14359/6965>.
- [44] Dymiotis C, Gutleiderer BM. Allowing for uncertainties in the modelling of masonry compressive strength. *Constr Build Mater* 2002;16:443–52. [https://doi.org/10.1016/S0950-0618\(02\)00108-3](https://doi.org/10.1016/S0950-0618(02)00108-3).
- [45] EN 1015-11:2019 - Methods of test for mortar for masonry - Part 11: Determination of flexural and compressive strength of hardened mortar. European Committee for Standardization, Brussels.
- [46] EN 1052-1. *Methods of test for masonry - Part 1: Determination of compressive strength*. Brussels: European Committee for Standardization; 1998.
- [47] EN 1996-1-1. *Eurocode 6: Design of masonry structures-Part 1-1: General rules for reinforced and unreinforced masonry structures*. Brussels: European Committee for Standardization; 2005.
- [48] EN 772-1:2011 - Methods of test for masonry units – Part 1: Determination of compressive strength. European Committee for Standardization, Brussels.
- [49] Engesser F. Über weitgespannte Wölbbrücken (in German). *Z Für Archit und Ing* 1907;53:403–40.
- [50] Fakharian P, Rezazadeh Eidaheeh D, Akbari M, Jahangir H, Ali Taeb A. Compressive strength prediction of hollow concrete masonry blocks using artificial intelligence algorithms. *Structures* 2023;47:1790–802. <https://doi.org/10.1016/j.istruc.2022.12.007>.
- [51] Fletcher R. *Practical methods of optimization*. New York: John Wiley & Sons; 1975.
- [52] Fonseca FS, Fortes ES, Parsekian GA, Camacho JS. Compressive strength of high-strength concrete masonry grouted prisms. *Constr Build Mater* 2019;202:861–76.
- [53] Fortes ES, Parsekian GA, Fonseca FS. Relationship between the Compressive Strength of Concrete Masonry and the Compressive Strength of Concrete Masonry Units. *J Mater Civ Eng* 2015;27:04014238. [https://doi.org/10.1061/\(ASCE\)MT.1943-5533.0001204](https://doi.org/10.1061/(ASCE)MT.1943-5533.0001204).
- [54] Francis AJ, Horman CB, Jerems LE. The effect of joint thickness and other factors on the compressive strength of brickwork, 2nd International brick masonry conference. Stoke-on-Trent 1970:31–7.
- [55] Furtado A, Rodrigues H, Arêde A, et al. Mechanical properties characterization of different types of masonry infill walls. *Front Struct Civ Eng* 2020;14:411–34.
- [56] Furtado A, Rodrigues H, Arêde A, Varum H. Experimental evaluation of out-of-plane capacity of masonry infill walls. *Eng Struct* 2016;111:48–63.
- [57] Garzón-Roca J, Marco CO, Adam JM. Compressive strength of masonry made of clay bricks and cement mortar: Estimation based on Neural Networks and Fuzzy Logic. *Eng Struct* 2013;48:21–7. <https://doi.org/10.1016/j.engstruct.2012.09.029>.
- [58] Gautam D, Adhikari R, Olafsson S, Rupakhty R. "Damage description, material characterization, retrofitting, and dynamic identification of a complex neoclassical monument affected by the 2015 Gorkha, Nepal earthquake". *J Build Eng* 2023;80:108152.
- [59] Gayed M., Korany Y., Sturgeon G. (2012). Examination of the prescribed concrete block masonry compressive strength in the Canadian masonry design standard, CSA S304. 1-04 15th International Brick and Block Masonry Conference, Florianópolis, Brazil, 2012.
- [60] Gholami M, Gholami A. Prediction of compressive strength of masonry structures: Integrating three optimized models by virtue of committee machine. *Structures* 2022;44:1127–37. <https://doi.org/10.1016/j.istruc.2022.08.079>.
- [61] Gholami M, Ranjbargol M, Yousefzadeh R, Ghorbani Z. Integrating three smart predictive models using a power-law committee machine for the prediction of compressive strength in masonry made of clay bricks and cement mortar. *Structures* 2023;55:951–64. <https://doi.org/10.1016/j.istruc.2023.06.058>.
- [62] Graus S, Vasconcelos G, Palha C. Experimental characterization of the deterioration of masonry materials due to wet and dry and salt crystallization cycles. In: Aguilar R, Torrevalva D, Moreira S, Pando MA, Ramos LF, editors. *Structural Analysis of Historical Constructions*. RILEM Bookseries, 18. Cham: Springer; 2019.
- [63] Gregoire Y. Compressive strength of masonry according to Eurocode 6: a contribution to the study of the influence of shape factors. *Mason Int, MI J Artic* 2007;20.
- [64] Gumaste KS, Nanjunda Rao KS, Venkatarama Reddy BV, Jagadish KS. Strength and elasticity of brick masonry prisms and walletes under compression. *Mater Struct* 2007;40:241–53. <https://doi.org/10.1617/s11527-006-9141-9>.
- [65] Haach V, Vasconcelos G, Lourenço PB. Experimental analysis of reinforced concrete block masonry walls subjected to in-plane cyclic loading. *J Struct Eng* 2010;136(4):452–62.
- [66] Hendry AW, Malek MH. Characteristic compressive strength of brickwork walls from collected test results. *Mason Int* 1986;7:15–24.
- [67] Hossain MM, Ali SS, Rahman MA. Properties of masonry constituents. *J Civ Eng* 1997;25(2):135–55.
- [68] Ip, F. (1999). "Compressive Strength and Modulus of Elasticity of Masonry Prisms", Master of Engineering Thesis, Carleton University, Ottawa.
- [69] Kaushik HB, Rai DC, Jain SK. Stress-Strain Characteristics of Clay Brick Masonry under Uniaxial Compression. *J Mater Civ Eng* 2007;19:728–39. [https://doi.org/10.1061/\(ASCE\)0899-1561\(2007\)19:9\(728\)](https://doi.org/10.1061/(ASCE)0899-1561(2007)19:9(728)).
- [70] Kennedy J, Eberhart R. Particle swarm optimization. *IEEE Int Conf Neural Netw - Conf Proc* 1995;4:1942–8.
- [71] Khalaf FM. Factors influencing compressive strength of concrete masonry prisms. *Mag Concr Res* 1996;48:95–101. <https://doi.org/10.1680/mac.1996.48.175.95>.
- [72] Khalaf FM, Hendry AW, Fairbairn DR. Study of the Compressive Strength of Blockwork Masonry. *SJ* 1994;91:367–75. <https://doi.org/10.14359/4139>.
- [73] Khan NA, Aloisio A, Monti G, Nuti C, Briseghella B. Experimental characterization and empirical strength prediction of Pakistani brick masonry walls. *J Build Eng* 2023;71:106451. <https://doi.org/10.1016/j.job.2023.106451>.
- [74] Köksal HO, Karakoç C, Yildirim H. Compression behavior and failure mechanisms of concrete masonry prisms. *J Mater Civ Eng* 2005;17:107–15. [https://doi.org/10.1061/\(ASCE\)0899-1561\(2005\)17:1\(107\)](https://doi.org/10.1061/(ASCE)0899-1561(2005)17:1(107)).
- [75] Kumavat HR. An experimental investigation of mechanical properties in clay brick masonry by partial replacement of fine aggregate with clay brick waste. *J Inst Eng India Ser A* 2016;97:199–204. <https://doi.org/10.1007/s40030-016-0178-7>.
- [76] Lourakis MIA. A brief description of the Levenberg-Marquardt algorithm implemented by levmar, Hellas (FORTH. Institute of Computer Science Foundation for Research and Technology; 2005. (<http://www.ics.forth.gr/~lourakis/levmar/levmar>).
- [77] Lourenço PB. Computations on historic masonry structures. *Prog Struct Eng Maths* 2002;4:301–19. <https://doi.org/10.1002/pse.120>.
- [78] Lourenço PB, Avila L, Vasconcelos G, et al. Experimental investigation on the seismic performance of masonry buildings using shaking table testing. *Bull Earthq Eng* 2013;11:1157–90.
- [79] Lourenço PB, Vasconcelos G, Medeiros P, Gouveia J. Vertically perforated clay brick masonry for loadbearing and non-loadbearing masonry walls. *Constr Build Mater* 2010;24(11):2317–30.
- [80] Loverdos D, Sarhosis V. Geometrical digital twins of masonry structures for documentation and structural assessment using machine learning. *Eng Struct* 2023;275:115256. <https://doi.org/10.1016/j.engstruct.2022.115256>.
- [81] Lumantarna R, Biggs DT, Ingham JM. Uniaxial compressive strength and stiffness of field-extracted and laboratory-constructed masonry prisms. *J Mater Civ Eng* 2014;26:567–75. [https://doi.org/10.1061/\(ASCE\)MT.1943-5533.0000731](https://doi.org/10.1061/(ASCE)MT.1943-5533.0000731).
- [82] Lundberg SM, Lee S-I. A unified approach to interpreting model predictions. : *Proc Proc 31st Int Conf Neural Inf Process Syst* 2017;2017:4768–77.
- [83] Machado J., Lübeck A., Mohamad G., Fonseca F., Santos Neto A., Compressive strength of masonry prisms under compression according to Eurocode 6 - EN 1996-1-1 (2005), Proceedings of the 13th North American Masonry Conference, Salt Lake City; 2019.
- [84] Mann W. Statistical evaluation of tests on masonry by potential functions. *Proc Sixth Int Brick Mason Conf Rome, Italy* 1982:86–98.
- [85] Martins ROG, Nalon GH, Alvarenga RSS, Pedrotti LG, Ribeiro JCL. Influence of blocks and grout on compressive strength and stiffness of concrete masonry prisms. *Constr Build Mater* 2018;182:233–41.
- [86] Mauro A. Long term effects of masonry walls. Italy: University of Roma; 2008.
- [87] McNary W, Abrams D. Mechanics of masonry in compression. *J Struct Eng* 1985; 111(4):857–70.
- [88] Medeiros P, Vasconcelos G, Lourenço PB, Gouveia J. Numerical modelling of non-confined and confined masonry walls. *Constr Build Mater* 2013;41:968–76.
- [89] Milani G, Lourenço PB, Tralli A. Homogenised limit analysis of masonry walls, Part I: failure surfaces. *Comput Struct* 2006;84:166–80. <https://doi.org/10.1016/j.compstruc.2005.09.005>.
- [90] Mishra M, Bhatia AS, Maity D. Support vector machine for determining the compressive strength of brick-mortar masonry using NDT data fusion (case study: Kharagpur, India). *SN Appl Sci* 2019;1:564. <https://doi.org/10.1007/s42452-019-0590-5>.
- [91] Mishra M, Bhatia AS, Maity D. Predicting the compressive strength of unreinforced brick masonry using machine learning techniques validated on a case study of a museum through nondestructive testing. *J Civ Struct Health Monit* 2020;10:389–403. <https://doi.org/10.1007/s13349-020-00391-7>.
- [92] Mishra M, Bhatia AS, Maity D. A comparative study of regression, neural network and neuro-fuzzy inference system for determining the compressive strength of brick-mortar masonry by fusing nondestructive testing data. *Eng Comput* 2021; 37:77–91. <https://doi.org/10.1007/s00366-019-00810-4>.
- [93] Mishra C., Yamaguchi K., Endo Y., Hanazato T., Mechanical Properties of Components of Nepalese Historical Masonry Buildings", Proceedings of International Exchange and Innovation Conference on Engineering & Sciences (IEICES) 4:2018.
- [94] Moayedian SM, Hejazi M. Estimating the modulus of elasticity and the compressive strength of brick, mortar and masonry at different scales. *Structures* 2024;61:106116. <https://doi.org/10.1016/j.istruc.2024.106116>.
- [95] Mohamad G., Comportamento mecanico na ruptura de prismas de blocos de concreto., Master Thesis, Univeridade Federal de Santa Catarina, Florianópolis; 1998.
- [96] Mohamad G, Lourenço PB, Roman HR. Mechanics of hollow concrete block masonry prisms under compression: review and prospects. *Cem Concr Compos* 2007;29(3):181–92.
- [97] Mohamad G., Lourenço P.B., Roman H.R., Mechanical behavior of concrete block masonry - Influence of vertical joint, 2011, 11th NAMC, Mineapolis, USA. (electronic source); 2011.

- [98] Mohebkhah A. A nonlinear-seismic model for brick-masonry-infill panels with openings in steel frames, Ph.D. thesis. Tehran (Iran): Tarbiat Modares University; 2007.
- [99] Motsa SM, Stavroulakis GE, Drosopoulos GA. A data-driven, machine learning scheme used to predict the structural response of masonry arches. *Eng Struct* 2023;296:116912. <https://doi.org/10.1016/j.engstruct.2023.116912>.
- [100] MSJC (Masonry Standards Joint Committee), 2013. Building Code Requirements and Specification for Masonry Structures. TMS 402/ACI 530/ASCE 5 and TMS 602/ACI 530.1/ASCE 6.
- [101] Muñoz R, Lourenço P, Moreira S. Experimental results on mechanical behaviour of metal anchors in historic stone masonry *Construction and Building Materials* 2018;163:643–55.
- [102] Nagarajan S, Viswanathan S, Ravi V. Experimental approach to investigate the behaviour of brick masonry for different mortar ratios. *Proc Int Conf Adv Eng Technol*, Singap, March, 2014 2014:586–92.
- [103] Nalon GH, Santos CFR, Pedroti LG, Ribeiro JCL, Veríssimo GDS, Ferreira FA. Strength and failure mechanisms of masonry prisms under compression, flexure and shear: Components' mechanical properties as design constraints. *J Build Eng* 2020;28:101038. <https://doi.org/10.1016/j.jobte.2019.101038>.
- [104] National Concrete Masonry Association (2012). Recalibration of the Unit Strength Method for Verifying Compliance with the Specified Compressive Strength of Concrete Masonry.
- [105] Nwofor TC. Experimental determination of the mechanical properties of clay brick masonry. *Can J Environ Constr Civil Eng* 2012;3(3).
- [106] Olatunji TM, Warwaruk J, Longworth J. Behavior and strength of masonry wall/slab joints. *Struct Eng Rep* 1986:139.
- [107] Oliveira J.V. (2014). Mechanical behavior of compressed earth blocks stabilized with alkaline activation. Master Thesis, University of Minho (in Portuguese).
- [108] Padalu PKVR, Singh Y. Variation in compressive properties of Indian brick masonry and its assessment using empirical models. *Structures* 2021;33:1734–53. <https://doi.org/10.1016/j.istruc.2021.05.063>.
- [109] Padalu PKVR, Singh Y, Das S. Uni-axial monotonic compressive properties of brick masonry in India. *Proceedings 10th Int Mason Conf (IMC)*, Pap ID: 639, 1st Ed 2018:1639–55. July 9–11, Milan, Italy.
- [110] Radovanović Ž, Sindjic-Grebovic R, Dimovski S, Serdar N, Vatin N, Murgul V. Testing of the mechanical properties of masonry walls – determination of compressive strength. *Appl Mech Mater* 2015;725-726:410–8.
- [111] Ramamurthy K, Sathish V, Ambalavanan R. Compressive Strength Prediction of Hollow Concrete Block Masonry Prisms. *SJ* 2000;97:61–7. <https://doi.org/10.14359/834>.
- [112] Raposo P, Furtado A, Arêde A, Varum H, Rodrigues H. Mechanical characterization of concrete block used on infill masonry panels. *Int J Struct Integr* 2018;9(3):281–95.
- [113] Ravula MB, Subramaniam KVL. Experimental investigation of compressive failure in masonry brick assemblages made with soft brick. *Mater Struct* 2017;50:19. <https://doi.org/10.1617/s11527-016-0926-1>.
- [114] Reddy BV, Vyas CVU. Influence of shear bond strength on compressive strength and stress-strain characteristics of masonry. *Mater Struct* 2008;41(10):1697–712.
- [115] Redmond TB, Allen MH. Compressive strength of composite brick and concrete masonry walls. *Mason Present Phila ASTM* 1975:195–232.
- [116] Roberts JJ. The effect of different test procedures upon the indicated strength of concrete blocks in compression. *Mag Concr Res* 1973;(83):87–98.
- [117] Sandeep MV, Renukadevi S, Manjunath S. Behavior of hollow concrete block masonry prism under compression-An experimental and analytical approach. *Int J Res Eng Technol (Electron Source)* 2013.
- [118] Sarhat SR, Sherwood EG. The prediction of compressive strength of ungrouted hollow concrete block masonry. *Constr Build Mater* 2014;58:111–21. <https://doi.org/10.1016/j.conbuildmat.2014.01.025>.
- [119] Sathiparan N, Jeyananthan P. Prediction of masonry prism strength using machine learning technique: effect of dimension and strength parameters. *Mater Today Commun* 2023;35:106282. <https://doi.org/10.1016/j.mtcomm.2023.106282>.
- [120] Sathiparan N, Rumeshekumar U. Effect of moisture condition on mechanical behavior of low strength brick masonry. *J Build Eng* 2018;17:23–31.
- [121] Segura J, Pelà L, Roca P. Monotonic and cyclic testing of clay brick and lime mortar masonry in compression. *Constr Build Mater* 2018;193:453–66.
- [122] Self, M.W. (1974), "The structural properties of load-bearing concrete masonry" EIES Proj D-622.
- [123] Sharafati A, Haji Seyed Asadollah SB, Al-Ansari N. Application of bagging ensemble model for predicting compressive strength of hollow concrete masonry prism. *Ain Shams Eng J* 2021;12:3521–30. <https://doi.org/10.1016/j.asej.2021.03.028>.
- [124] Shivaraj Kumar HY, Renuka Devi MV, Sandeep, Manjunath S, Somanath MB. Effect of prism height on strength of reinforced hollow concrete block masonry. *Int J Res Eng Technol* 2014;03(06) (electronic source).
- [125] Singh SB, Munjal P. Bond strength and compressive stress-strain characteristics of brick masonry. *J Build Eng* 2017;9:10–6.
- [126] Skentou AD, Bardhan A, Mamou A, Lemonis ME, Kumar G, Samui P, Armaghani DJ, Asteris PG. Closed-form equation for estimating unconfined compressive strength of granite from three non-destructive tests using soft computing models. *Rock Mech Rock Eng* 2023;56(2023):487–514. <https://doi.org/10.1007/s00603-022-03046-9>.
- [127] Soundar Rajan M, Jegatheeswaran D. Prediction of autoclaved aerated cement block masonry prism strength under compression using machine learning tools. *Matéria (Rio J)* 2024;29(1):e20230247.
- [128] Standoli G, Salachoris GP, Masciotta MG, Clementi F. Modal-based FE model updating via genetic algorithms: Exploiting artificial intelligence to build realistic numerical models of historical structures. *Constr Build Mater* 2021;303:124393. <https://doi.org/10.1016/j.conbuildmat.2021.124393>.
- [129] Tassios TP. *Meccanica delle Murature*. Napoli: Liguori Editore; 1988.
- [130] Tassios T.P., Chronopoulos M.P., A seismic dimensioning of interventions (repairs/strengthening) on lowstrength masonry building. Presented at the Middle East and Mediterranean Regional Conference on Earthen and low-strength masonry buildings in seismic areas, Ankara, Turkey; 1986.
- [131] Thaickavil NN, Thomas J. Behaviour and strength assessment of masonry prisms. *Case Stud Constr Mater* 2018;8:23–38. <https://doi.org/10.1016/j.cscm.2017.12.007>.
- [132] Thamboo JA. *Development of Thin Layer Mortared Concrete Masonry* (Ph.D. Dissertation). Brisbane: Queensland University of Technology; 2014.
- [133] Thamboo JA. Material characterisation of thin layer mortared clay masonry. *Constr Build Mater* 2020;230:116932.
- [134] Thamboo JA, Dhanasekar M. Correlation between the performance of solid masonry prisms and walleets under compression. *J Build Eng* 2019;22:429–38. <https://doi.org/10.1016/j.jobte.2019.01.007>.
- [135] Valero E, Forster A, Bosché F, Hyslop E, Wilson L, Turmel A. Automated defect detection and classification in ashlar masonry walls using machine learning. *Autom Constr* 2019;106:102846. <https://doi.org/10.1016/j.autcon.2019.102846>.
- [136] Vermeltfoort AT. Compression properties of masonry and its components. *Proc 10th Int Brick Block Mason Conf*, Can 1994;3:1433–42.
- [137] Vimala S, Kumarasamy K. Studies on the strength of stabilized mud block masonry using different mortar proportions. *Int J Emerg Technol Adv Eng* 2014;4(4):720–4.
- [138] Vindhyashree, Rahamath A, Kumar WP, Kumar MT. Numerical simulation of masonry prism test using ANSYS and ABAQUS. *Int J Eng Res Technol* 2015;4(7):1019–27.
- [139] Vyas U, Reddy V. Prediction of solid block masonry prism compressive strength using FE model. *Mater Struct* 2010;43:719–35. <https://doi.org/10.1617/s11527-009-9524-9>.
- [140] Wang N, Zhao X, Zhao P, Zhang Y, Zou Z, Ou J. Automatic damage detection of historic masonry buildings based on mobile deep learning. *Autom Constr* 2019;103:53–66. <https://doi.org/10.1016/j.autcon.2019.03.003>.
- [141] Yang K-H, Lee Y, Hwang Y-H. A stress-strain model for brick prism under uniaxial compression. *Adv Civ Eng* 2019;2019:1–10. <https://doi.org/10.1155/2019/7682575>.
- [142] Zahra T, Thamboo J, Asad M. Compressive strength and deformation characteristics of concrete block masonry made with different mortars, blocks and mortar beddings types. *J Build Eng* 2021;38:102213.
- [143] Zavalis R, Jonaitis B, Lourenço P. Experimental investigation of the bed joint influence on mechanical properties of hollow calcium silicate block masonry. *Mater Struct* 2018;51:85.
- [144] Zhou Q, Wang F, Zhu F. Estimation of compressive strength of hollow concrete masonry prisms using artificial neural networks and adaptive neuro-fuzzy inference systems. *Constr Build Mater* 2016;125:417–26. <https://doi.org/10.1016/j.conbuildmat.2016.08.064>.