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DOME-SHAPED BUILDINGS FOR REDUCING FOUNDATION LOADS: A COMPARATIVE STUDY

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Abstract

Increasing urban density and the expansion of construction into weak or deformation-sensitive ground have renewed interest in structural systems that can reduce foundation demand at the source. This study examines whether a dome-shaped building envelope can lower the gravity load transmitted to the ground relative to a conventional two-storey rectilinear building with comparable usable floor area. The work is a comparative analytical case study rather than a full structural or geotechnical design. Geometry reported in the source concept is retained: approximately 218 m² of external surface for the dome-shaped alternative and 324 m² for the conventional alternative, with an approximately 80 m² plan area and a comparable overall height. Using a common envelope unit weight of 0.5 kN/m², the corresponding envelope self-weights are 109 kN and 162 kN. The dome option therefore reduces this modeled component of gravity load by 53 kN, or 32.7%. If the same 80 m² effective foundation area is used only for a first-order comparison, average pressure associated with that envelope component decreases from 2.03 kPa to 1.36 kPa. A sensitivity analysis confirms that the percentage reduction remains controlled by geometric surface-area efficiency when identical unit weights are assumed. The results support dome geometry as a potentially efficient load-reduction strategy, while also showing that claims regarding actual settlement, bearing capacity, seismic performance, and local contact-pressure uniformity require soil parameters, complete load combinations, support details, and soil–structure interaction analysis. The study

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therefore provides a defensible preliminary screening method and a framework for subsequent finite-element and field validation.

Keywords: Dome structure; shell action; soil–structure interaction; foundation pressure; structural self-weight; settlement; sustainable structural design.

1. Introduction

In dense urban environments, foundation performance is increasingly affected by higher structural loads, limited construction footprints, adjacent foundations, variable ground conditions, and stricter serviceability requirements. In such settings, the structural form itself can become an important geotechnical design variable. A building system that achieves the required usable volume with less structural material may reduce permanent actions, foundation reactions, and the stress increment imposed on the supporting ground. Modern geotechnical design explicitly treats foundation displacement and differential movement as serviceability considerations [1].

Conventional low- and mid-rise buildings commonly rely on walls, frames, slabs, and roof systems that transfer gravity loads through discrete vertical members or wall lines. The resulting foundation reactions depend on the stiffness of the superstructure, foundation configuration, load eccentricity, and ground stiffness. By contrast, dome and shell systems use curvature to mobilize in-plane membrane forces over a continuous surface. Shell research consistently identifies membrane-dominated action as a central reason for the high structural efficiency of curved surfaces, especially under appropriately distributed gravity loading [2–6]. However, shell efficiency does not automatically imply uniform soil pressure: boundary conditions, ring forces, openings, asymmetric loading, foundation stiffness, and soil heterogeneity can introduce bending and localized reactions. The original concept underlying this study compares a dome-shaped two-level enclosure with a conventional rectilinear building of similar functional floor area.

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The source document reports external surface areas of about 218 m² and 324 m², respectively, and argues that the smaller envelope may lower structural self-weight and thereby reduce demand on the ground. The source also gives a simple numerical example based on an envelope unit weight of 0.5 kN/m². These values are retained here as the core dataset, but the analysis is reformulated into a transparent IMRAD structure and the conclusions are narrowed to quantities that can be supported by the available data.

The purpose of this paper is therefore not to claim a complete geotechnical advantage for dome buildings. Instead, it aims to answer a more precise question: under equal envelope unit weight and comparable effective foundation area, how much can the reported geometric reduction in external surface area reduce one modeled component of permanent load and its corresponding first-order average ground pressure? The study also identifies which additional variables must be measured or modeled before settlement and foundation performance can be predicted reliably.

The contribution of the paper is threefold. First, it converts the source concept into a reproducible comparative calculation. Second, it separates geometry-driven findings from unverified assumptions about soil response. Third, it proposes a staged validation pathway that links preliminary architectural geometry to structural analysis, foundation modeling, and geotechnical serviceability checks. This distinction is particularly important because settlement and differential movement must be evaluated using relevant ground parameters, load distributions, and structural stiffness rather than inferred from total load reduction alone [1].

1.1. Structural and geotechnical background

Thin shells and domes are efficient when loads can be carried primarily through membrane forces. Classical shell theory and modern analytical studies show that curvature allows distributed loads to be transferred through meridional and

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circumferential force resultants, thereby reducing the bending demand that dominates many planar structural systems [3–6]. Investigations of dome shells also demonstrate the importance of stability and support conditions in determining actual structural behavior [2,3].

Nevertheless, efficient shell behavior is conditional. Concentrated loads, geometric discontinuities, stiff supports, large openings, and unsymmetrical actions may produce local bending and stress concentrations [4–6]. For dome-supported buildings, the lower edge typically develops horizontal thrust or ring-force effects that must be resolved by an edge beam, tension ring, buttressing system, or foundation arrangement. Consequently, the superstructure–foundation interface remains a critical design region.

From the geotechnical perspective, average foundation pressure is only a screening indicator. Settlement depends on the magnitude and spatial distribution of stress increase, soil compressibility, drainage conditions, stress history, foundation width and embedment, interaction with adjacent foundations, and time-dependent consolidation or creep. Eurocode 7 requires consideration of total and differential foundation movements and notes the approximate nature of settlement calculations [1]. Uzbekistan’s current foundation standard, ShNQ 2.02.01-24, forms part of the national regulatory framework for the design of building and structure foundations [7], while national loading requirements are addressed in QMQ 2.01.07-21 [8].

These considerations motivate a cautious interpretation: reducing structural self-weight is beneficial because it reduces a component of permanent action, but the actual effect on foundation size, bearing resistance, and settlement can only be determined after all relevant actions and ground properties are included.

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2. Materials and Methods

2.1. Study design and source geometry

The research uses a deterministic comparative case-study method. Two conceptual building forms are compared using the geometric data provided in the source document: (i) a dome-shaped two-level building and (ii) a conventional two-level rectilinear building. Each level is represented as providing approximately 80 m² of usable floor area. The external surface area reported for the dome-shaped option is 218 m², whereas the corresponding surface area for the conventional alternative is 324 m². The comparison is intended to isolate geometric envelope efficiency; it is not a complete bill of quantities.

The diagram in Figure 1 reproduces the source comparison. Its principal analytical role is to establish the reported surface-area values and the comparable floor-area basis. Because the source image does not provide a full structural specification, no assumptions are made about exact member sizes, reinforcement ratios, glazing, internal partitions, mechanical equipment, foundation thickness, or connection detailing.

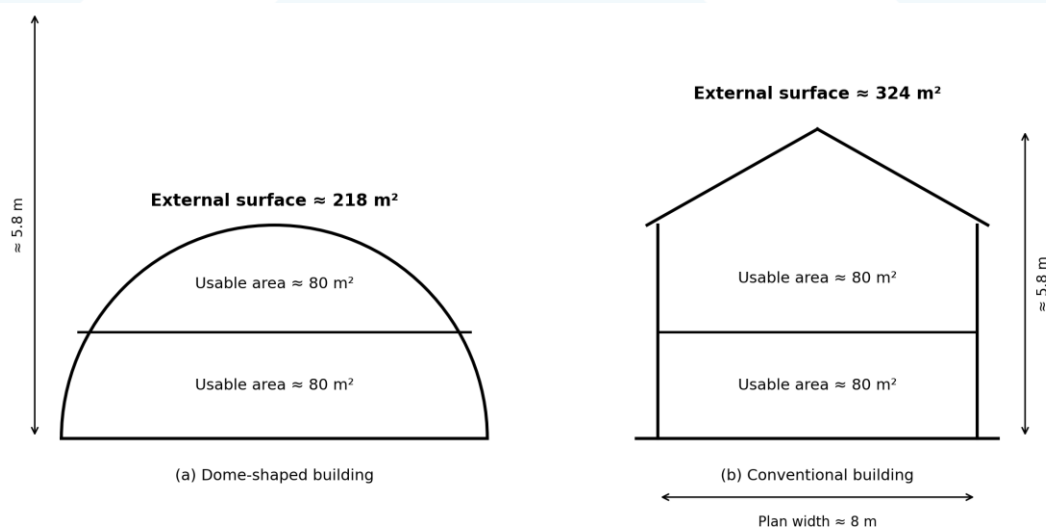


Figure 1. Comparative schematic of the dome-shaped and conventional two-storey building forms. Reported external surface areas are approximately 218 m² and 324 m², respectively.

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2.2. Analytical model

The primary calculation considers only the self-weight of the external enclosing system. A common surface unit weight, $w = 0.5 \text{ kN/m}^2$, is adopted from the source example to preserve comparability. The envelope load W is calculated as:

$$W = A \times w \quad (1)$$

where W is the modeled envelope self-weight (kN), A is the external surface area (m^2), and w is the assumed surface unit weight (kN/m^2). The relative load reduction R is evaluated by:

$$R = (W_{\text{conv}} - W_{\text{dome}}) / W_{\text{conv}} \times 100\% \quad (2)$$

For a first-order pressure comparison, both alternatives are assigned the same effective foundation area, $A_f = 80 \text{ m}^2$. This is deliberately simplified and should not be interpreted as an actual foundation design. The corresponding average pressure contribution q is:

$$q = W / A_f \quad (3)$$

Because both alternatives use the same assumed foundation area and the same envelope unit weight, the percentage reduction in this modeled average pressure is identical to the percentage reduction in external surface area. In practice, contact pressure is governed by foundation stiffness, load paths, eccentricity, soil stiffness, and soil–structure interaction; therefore Equation (3) is used only as a screening metric.

2.3. Sensitivity analysis

To test whether the conclusion depends on the selected envelope weight, the calculation is repeated for $w = 0.3, 0.5, 0.8$, and 1.0 kN/m^2 . A second sensitivity check varies the assumed effective foundation area from 60 to 100 m^2 . These ranges do not represent code-prescribed values; they are analytical scenarios used to show which outputs are controlled by geometry and which depend on the assumed support area.

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2.4. Scope, assumptions, and validity limits

- Only the external envelope self-weight is modeled; floor slabs, internal partitions, live loads, snow, wind, seismic actions, mechanical systems, finishes, foundations, and nonstructural equipment are excluded.
- Both alternatives are assumed to use the same envelope unit weight in the base comparison.
- The reported external surface areas (218 and 324 m²) are taken directly from the source concept and are not independently reconstructed from detailed geometry.
- The 80 m² effective foundation area is a screening assumption, not a designed footing or raft area.
- No site-specific soil parameters are available; therefore bearing capacity and settlement are not calculated.
- No claim of measured pressure uniformity is made. Membrane action is discussed as a structural mechanism, but local foundation reactions require structural and soil–structure interaction analysis.

3. Results

3.1. Geometry-driven reduction in envelope area and self-weight

The dome-shaped alternative uses 106 m² less external surface area than the conventional alternative. Relative to 324 m², this is a 32.7% reduction. Under the common unit-weight assumption of 0.5 kN/m², envelope self-weight decreases from 162 kN to 109 kN, producing a 53 kN reduction. Because the unit weight is identical, the load-reduction ratio is exactly the surface-area-reduction ratio.

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Table 1. Base-case comparative calculations.

Parameter	Conventional	Dome-shaped	Absolute difference	Relative change
External surface area, m ²	324	218	106	−32.7%
Envelope unit weight, kN/m ²	0.50	0.50	0	0%
Envelope self-weight, kN	162	109	53	−32.7%
Effective foundation area, m ²	80	80	0	0%
Average pressure contribution, kPa	2.03	1.36	0.67	−32.7%

3.2. Average pressure screening

Using the common 80 m² effective foundation area, the modeled envelope component contributes an average pressure of 2.03 kPa in the conventional alternative and 1.36 kPa in the dome-shaped alternative. The absolute difference is 0.67 kPa. This result should be interpreted as the reduction attributable to the modeled envelope component only; total design pressure would be substantially affected by the self-weight of floors and foundations, occupancy loads, and environmental actions.

3.3. Sensitivity to envelope unit weight

Table 2. Sensitivity of modeled envelope load and average pressure to envelope unit weight ($A_f = 80 \text{ m}^2$).

w (kN/m ²)	W _{conv} (kN)	W _{dome} (kN)	ΔW (kN)	q _{conv} (kPa)	q _{dome} (kPa)
0.3	97.2	65.4	31.8	1.22	0.82
0.5	162.0	109.0	53.0	2.02	1.36
0.8	259.2	174.4	84.8	3.24	2.18
1.0	324.0	218.0	106.0	4.05	2.73

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The absolute load saving increases linearly with unit weight, from 31.8 kN at 0.3 kN/m² to 106 kN at 1.0 kN/m². However, the percentage saving remains 32.7% throughout because both alternatives use the same unit weight. Thus, within this simplified model, the comparative advantage is geometric rather than material-specific.

3.4. Sensitivity to effective foundation area

Table 3. Sensitivity of the modeled average pressure contribution to assumed effective foundation area ($w = 0.5$ kN/m²).

Af (m ²)	qconv (kPa)	qdome (kPa)	Difference (kPa)
60	2.70	1.82	0.88
70	2.31	1.56	0.76
80	2.02	1.36	0.66
90	1.80	1.21	0.59
100	1.62	1.09	0.53

As the assumed support area increases, both average pressure values decrease. The relative difference remains 32.7%, whereas the absolute pressure difference decreases from 0.88 kPa at 60 m² to 0.53 kPa at 100 m². This illustrates why average pressure alone cannot establish settlement performance: settlement depends not only on total vertical force but also on foundation width, stress distribution with depth, soil stiffness, and drainage conditions.

4. Discussion

4.1. Interpretation of the main finding

The robust result of the present case study is narrow but useful: if two buildings provide comparable functional floor area and use the reported external surface areas, the dome-shaped option requires about one-third less envelope area. When the same envelope unit weight is applied, the corresponding envelope self-weight is also reduced by about one-third. This is a transparent geometric consequence

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and does not depend on a particular soil model. The result is compatible with the established efficiency of dome and shell forms under favorable loading and support conditions [2–6].

This finding is consistent with the broader structural logic of shells. Curved structural surfaces can achieve high efficiency by transferring distributed loads through membrane action, and dome forms have long been used where large enclosed volumes and low structural mass are desirable. Yet the current calculation does not quantify membrane stresses, buckling capacity, edge-ring forces, or second-order effects. Those issues must be resolved before the lighter envelope can be translated into a complete structural design.

The geotechnical implication is that reducing permanent structural actions can reduce one component of foundation demand. For a site where serviceability is governed by stress-induced settlement, a lower applied load is generally favorable. However, the magnitude of settlement reduction cannot be inferred directly from the 32.7% load reduction because real ground response is nonlinear and depends on stress level, soil type, consolidation state, foundation geometry, embedment, groundwater conditions, and structural stiffness. Accordingly, statements such as 'settlement decreases two or three times' would not be defensible without site-specific analysis or measurements.

4.2. Load distribution and soil–structure interaction

A common qualitative argument for dome systems is that loads are distributed more evenly because the shell works as a continuous spatial system. At the superstructure level, this description can be reasonable under symmetric loading and suitable support conditions [3–6]. At the foundation level, however, contact-pressure uniformity is not guaranteed. Foundation pressure depends on the interaction between applied reactions, foundation rigidity, and ground response [9,10]. A dome may deliver substantial circumferential forces to its base, and a

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ring foundation can develop nonuniform reactions if stiffness, geometry, or ground conditions vary around the perimeter.

Therefore, a defensible evaluation should couple a shell model with a foundation and ground model. At minimum, the next stage should compare reaction distributions at the dome support ring and at the conventional wall or column foundations under identical gravity load combinations. A more advanced model should represent the ground with appropriate constitutive behavior and assess settlement, differential settlement, contact pressure, and potentially uplift or loss of contact under asymmetric actions. Earlier experimental and analytical work on dome–soil systems also illustrates that surrounding soil can substantially alter load transfer and stability, reinforcing the need for coupled analysis rather than isolated shell calculations [10,11].

4.3. Practical implications for sustainable design

The 32.7% reduction in modeled external surface area may also have material and operational implications beyond foundation demand. A smaller envelope can reduce the quantity of cladding, insulation, weatherproofing, and associated support elements when comparable material systems are used. In turn, lower material quantities may reduce embodied impacts. However, dome geometry can also complicate fabrication, openings, interior fit-out, façade detailing, and construction logistics. A sustainability assessment should therefore compare complete life-cycle material quantities and construction processes rather than relying on surface area alone.

For weak or settlement-sensitive ground, light structural systems are often attractive because they may allow smaller foundations or reduce ground-improvement demand. The present analysis suggests that dome geometry can be included in early-stage option screening. It should not replace geotechnical investigation or code-based foundation verification.

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4.4. Proposed validation framework

The preliminary model can be advanced through a four-stage validation framework. Stage 1 should reconstruct both alternatives in a consistent three-dimensional geometry and generate a complete quantity take-off. Stage 2 should perform structural finite-element analysis under permanent, imposed, wind, snow, and seismic actions, including geometric imperfections and support-ring effects for the dome. Stage 3 should transfer the resulting reactions to a geotechnical soil–structure interaction model calibrated using site investigation data. Stage 4 should validate selected outputs using field instrumentation, plate or footing response data, settlement monitoring, or a scaled physical model. The principal comparison metrics should include total permanent load, peak and mean contact pressure, pressure coefficient of variation, maximum settlement, differential settlement, foundation material quantity, and global safety margins.

4.5. Limitations

The main limitation is the restricted input dataset. The source concept provides envelope areas and a simplified unit-weight example, but not a complete structural system, material schedule, site investigation, or foundation layout. Consequently, the paper cannot establish actual bearing capacity, settlement, differential settlement, structural safety, or construction cost.

A second limitation is geometric equivalence. Although both concepts are presented with comparable floor area, a dome and a rectilinear building may differ in usable perimeter zones, headroom, façade openings, and internal planning efficiency. Future work should compare gross floor area, net usable area, enclosed volume, and envelope area simultaneously.

A third limitation is that identical envelope unit weight favors a clean geometric comparison but may not reflect real construction. Dome cladding and shell systems can be lighter or heavier than conventional walls and roofs depending on material, insulation, framing, connections, and fire-performance requirements.

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Therefore, the current results should be considered a normalized benchmark rather than a final design outcome.

5. Conclusions

1. Using the source geometry, the dome-shaped alternative has an external surface area of 218 m² compared with 324 m² for the conventional alternative, a reduction of 32.7%.
2. With a common envelope unit weight of 0.5 kN/m², modeled envelope self-weight decreases from 162 kN to 109 kN, saving 53 kN.
3. Using the same 80 m² effective support area for screening purposes, the corresponding average pressure contribution decreases from 2.03 kPa to 1.36 kPa. This is not a complete foundation pressure calculation.
4. The percentage reduction is robust to changes in common envelope unit weight because it is governed by the reported surface-area ratio. Absolute savings increase with heavier envelope systems.
5. The available data do not justify numerical claims about actual settlement reduction or perfectly uniform ground pressure. Those outputs require complete structural reactions, site-specific soil properties, foundation stiffness, and soil–structure interaction analysis.
6. Dome-shaped systems should therefore be treated as a promising early-stage strategy for reducing structural self-weight and potentially foundation demand, subject to verification by detailed structural, geotechnical, constructability, and life-cycle assessment.

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