Hybrid Typologies: Quantifying the Operational Energy, Embodied Energy, and First Cost of Emergent Light-Wood-Framed Multifamily Construction Methods

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Abstract

Historically, large apartment developments in the United States likely took one of two forms: low-rise garden apartments which offered low construction costs associated with light wood framing, or high-rise apartment buildings which were more costly but afforded greater density. Low-rise garden apartments could be build using inexpensive dimension lumber, but were limited to densities of 25-40 units-per-acre. Conversely, high-rise projects had no density limitations, but required construction using more costly fire-resistive and/or non-combustible construction.

In recent years, new typologies have emerged which seek to combine the cost effectiveness of light-wood framing with the higher densities of fire-resistive construction by combining construction types in the same building. Two popular versions of these typologies are the podium building and the wrap/donut building. These buildings allow for the construction of densities which can be more quadruple garden apartments without abandoning the cost effectiveness of light wood framing.

The construction of wrap and podium buildings has exploded, with subtypes such as the "Texas Donut" and the "Five-Over-One" now dominating new multifamily construction. Unfortunately, the scholarly understanding of these buildings has lagged behind their implementation, creating difficulty in quantifying their impact in terms of first cost, operational energy use, and embodied energy performance relative to other common multifamily types.

In this paper, we propose using permit, bid, and construction documents from recently completed projects to develop four prototype buildings, each housing the same number of units of the same size and varying construction types and representing, respectively, garden apartments, wrap buildings, podium buildings, and conventional high-rise buildings. We propose comparatively evaluating these four types, the first and last of which represent conventional solutions while the middle two represent new hybrid solutions. Evaluation will be conducted for operational energy use using an hourly energy model, embodied energy of materials using a detailed three-dimensional structural model, and cost, using quantities from the previous models in concert with industry-standard cost estimation resources such as RSMeans.

In doing so, we hope to create a "base case" understanding of light-framed podium and wrap buildings, which will allow for better accounting of their environmental and economic impact relative to the traditional garden apartment and high-rise apartment types.

1.0 Introduction

At present, the US houses approximately 32 million units of multifamily housing, of which over 22 million are in buildings with greater than five units[i]. While smaller courtyard or three-flat buildings were once common, increasingly, new multifamily projects are larger, with the average new construction project now housing 129 units. In the Sun Belt, growth of new multifamily housing has been explosive, with recent reports indicating that cities including Austin, Dallas, Miami, Nashville, Raleigh, and Salt Lake City, currently have a number of units in their respective "pipelines" equal to at least ten percent of overall inventory, suggesting a doubling of multifamily capacity within a decade or less in each city[ii].

In the United States, the least expensive way to build multifamily housing has historically been using light-wood dimension lumber framing[iii]. This type of construction has historically been governed by the restriction to Type-V Construction in the International Building Code. However, recent changes to the code and emergence of fire-retardant wood framing products have resulted in increasingly large multifamily projects being constructed of wood in the early decades of the 21st century[iv].

Specifically, changes to the way in which height and area limitations were "counted" for projects utilizing more than one type of construction were made in 2012, allowing the combination of light-wood framing with other types in substantially larger multi-family projects. As a result of this, projects with light-wood-framing above a non-combustible (i.e. Type-I) podium began to emerge a way to achieve the density more typical to high-rise construction with the lower cost associated with lightwood framing[v].

Despite the often-maligned appearance of these types of projects, two new typologies have become ubiquitous in American cities and suburbs[vi]. The first type, known colloquially as the "wrap" or "donut" utilized up to four-floors of light-wood framing "wrapped" around a non-combustible structured parking garage. As Type-V construction is the least restrictive in terms of fire rating of assemblies, these projects offered low costs and higher densities than had been traditional achieved with light-wood framed apartments. These projects also allowed for the concealment of structured parking deep inside of the building floor-plate, by "wrapping" unsightly garages with street-facing residential units.

Because the wrap utilizes light-wood framing with minimal fire-rating, the residential components of these projects are generally limited to four-stories in height. For projects requiring greater density, another hybrid-solution emerged, the podium-type. Often called "five-over-ones" or "four-over-ones" or similar names, these structures combined a non-combustible base with light wood framing above. This allowed for either four stories or five-stories of light wood framing above a podium with up to two stories of above-grade Type-I construction, for possible densities of up to seven stories above grade.

Despite the prevalence of these new solutions, relatively little has been written about them in the academic literature. Because they are generally unique to North America, international scholarship has tended to avoid considering them. Meanwhile, domestic scholarship has generally focused on their density and potential roll as urban infill[vii], paying much less attention to their tectonics.

This discrepancy between the type's ubiquity among new construction projects and their comparative absence from the literature makes building-level evaluations of these types difficult. While comparisons of cost, operational energy, and embodied energy across residential typologies have been previously completed[viii], they have often focused on disparate ends of the density spectrum[ix], with less attention paid to new, hybrid forms.

In the following sections, we develop a model for comparison of these new types with historical, better understood modalities along three axes: embodied carbon, operational carbon, and economic first-cost. We thus compare the following four typologies, holding steady the number and size of units across each solution:

1. Two-story breezeway apartment building with tuck-under parking (Type V Construction)
2. Four-story Wrap/Donut building with interior structure parking (Type V around Type II)
3. Seven-story Podium Building with structure parking at ground plinth (Type III over Type I)
4. Ten story Highrise tower over structured parking (Type I).

Section 2 discusses each project in more detail. Section 3 introduces the method by which each solution was evaluated and discusses the results of the evaluation, while Section 4 discusses the approach's limitations and opportunities for further research.

2.0 Four Typological Models

For theoretical building models were developed, representing the four aforementioned types. Each solution housed the same number of residential units of the same type: 250 total units consisting of 120 one-bedroom units of approximately 750 net rentable square feet, 80 two-bedroom units of approximately 1,000 net rentable square feet, and 50 three-bedroom units of approximately 1,250 net rentable square feet. Each type also provided covered parking at a ratio of one-per-residential unit, and approximately 12,000 gross square feet of leasing office and amenity space. Each type is discussed in greater detail below.

Note that the images shown for each typology, while simplified, maintain consistency in terms of color. Light blue is used in images to represent conditioned common areas, such as amenities and circulation space. Red-orange is used to show structured parking and utility spaces which are typically unconditioned. Green, gray, and purple represent one, two, and three-bedroom units, respectively.

2.1 Type A: Garden Apartments

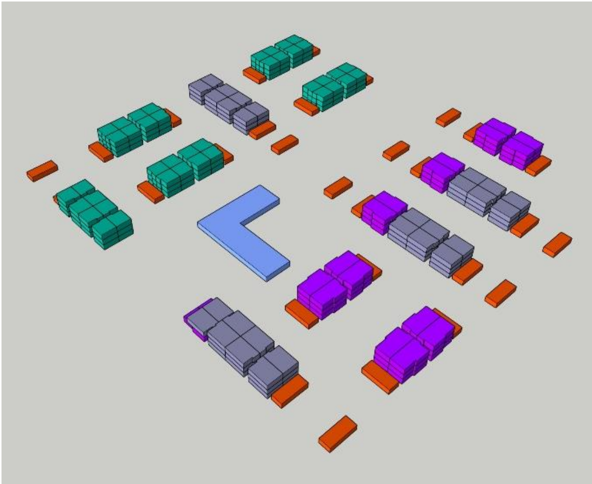

Figure 1: Garden Apartment Massing Model

As shown in *Figure 1*, the lowest density considered was a garden apartment projects in which all units were housed in three-story breezeway-type walk-up buildings scattered across a 16 acre site, for a density of between 15-20 units per acre. The size of each building was limited by the footprint outlined in the code, with bonus maximum areas achieved by spacing the buildings in such away as to qualify for the maximum open-space bonus. Parking was provided by a combination of interior-single-stall garages and covered-surface parking. Construction was of Type V, with minimal fire-rated assemblies.

2.2 Type B: Wrap/Donut

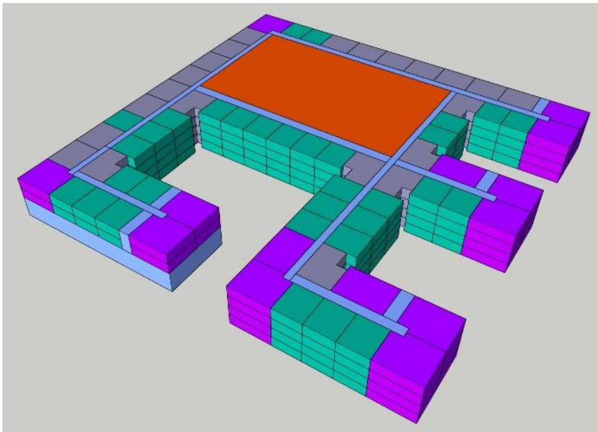

Figure 2: Wrap/Donut Building Massing Model

The second level of density considered was the first of the new hybrid-typologies, the "wrap/donut" building (shown in *Figure 2*). This solution combined low-rise Type-V construction wrapped around a non-combustible Type-II pre-cast concrete structured parking garage. Single-loaded corridors were used immediately adjacent to the garage (the "wrap"), while double loaded corridors around interior courtyards (the "donut") were used elsewhere on-site. The project achieves a density of 60-65 units per acre.

2.3 Type C: Five-Over-Two Podium

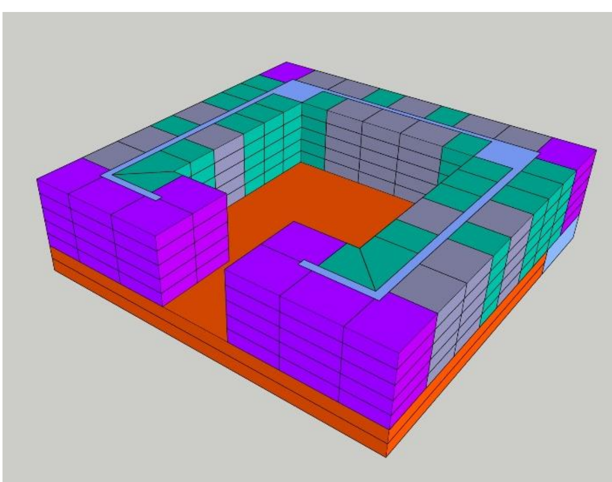

Figure 3: Five-Over-Two Podium Massing Model

The third level of density represents the slightly denser hybrid typology, utilizing a two-story podium of fire-resistive (Type I) construction housing structured parking and amenities, above which are provided five-floors of Type-III ordinary construction, creating a "five-over-two" podium solution. The upper floors are organized around a double-loaded corridor in "U" shape, achieving the efficiency necessary for a density of 125 units per acre. This solution is shown in *Figure 3*.

2.4 Type D: High-Rise

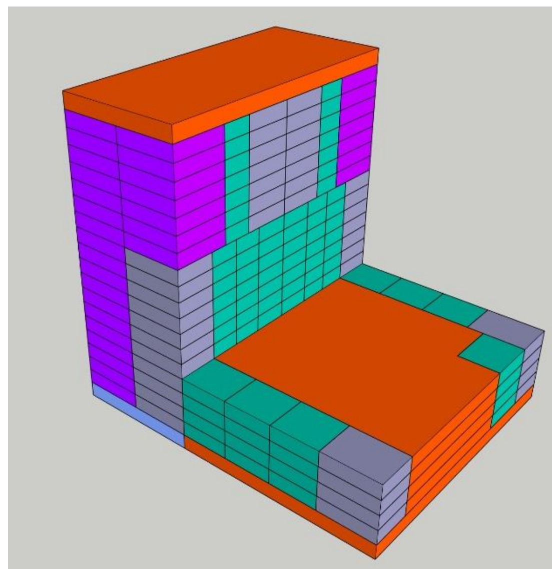

Figure 4: High-Rise Massing Model

Finally, representing the upper-level of the density spectrum, the Type-I high-rise is a 20-story building with residential units on floors 2-19 with an integrated parking garage (*Figure 4*). It is of flat-plate post-tensioned concrete construction with a five-story tower plinth topped with a 15-story tower block. It manages to fit all 250 residential units and associated parking on a single acre.

The internal circulation of some solutions compared to the exterior circulation of others, along with the net-to-gross efficiency associated with each type, lead to slight deviations in the overall gross-floor-area. To ensure an "apples-to-apples" comparison, the sizes of the units and the number of parking spaces were held constant, regardless of the overall gross floor area. While taller buildings generally include more glazing, often being finished with window-wall or curtain-wall, to ensure comparability, window wall ratio for each tower was held constant between the code minimum (defined as 8% of the floor area for occupied spaces) and maximum (defined as 30% of the exterior wall area) at 20%.

3.0 Three Methods of Evaluation

For each of the four typologies, three digital models were constructed for evaluation, all based on the same plan organization. The first model evaluated construction first-cost, and was generating using RS-Means 2024[x] cost estimating database. The second evaluated embodied carbon and was generated using Athena Impact Estimator for Buildings Version 5.5. The third-and-final model of each solution was constructed in Rhino and evaluated using the Grasshopper visual programing engine in concert with the Honeybee and Ladybug plug-ins. More methodological information along with results are provided below.

3.1 Evaluating Construction First-Cost

The initial construction cost of each type was evaluating using the assembly method on per-unit-floor area basis within RS Means. Data was from Quarter 4 of 2024, the most recent available. Standard Union Labor was assumed, and national averages were used to provide the broadest possible picture.

Certain assumptions were necessary to simplify the estimation. For example, only hard-costs were considered, with the costs of design, entitlements, and land not accounted for. Also, because each solution would have utilized similar interior finishes, casework, fixtures, etc., these were omitted from the model. Mechanical, electrical, plumbing, and fire-protection systems were also omitted. Thus, the figures reported below represent perhaps half of the hard costs of each building, and an even smaller share of overall project costs (inclusive of soft costs, land costs, and gray-area costs). Ergo, the figures should not be interpreted as representative of overall building costs but are for comparative purposes only. The results are shown in *Figure 5* below.

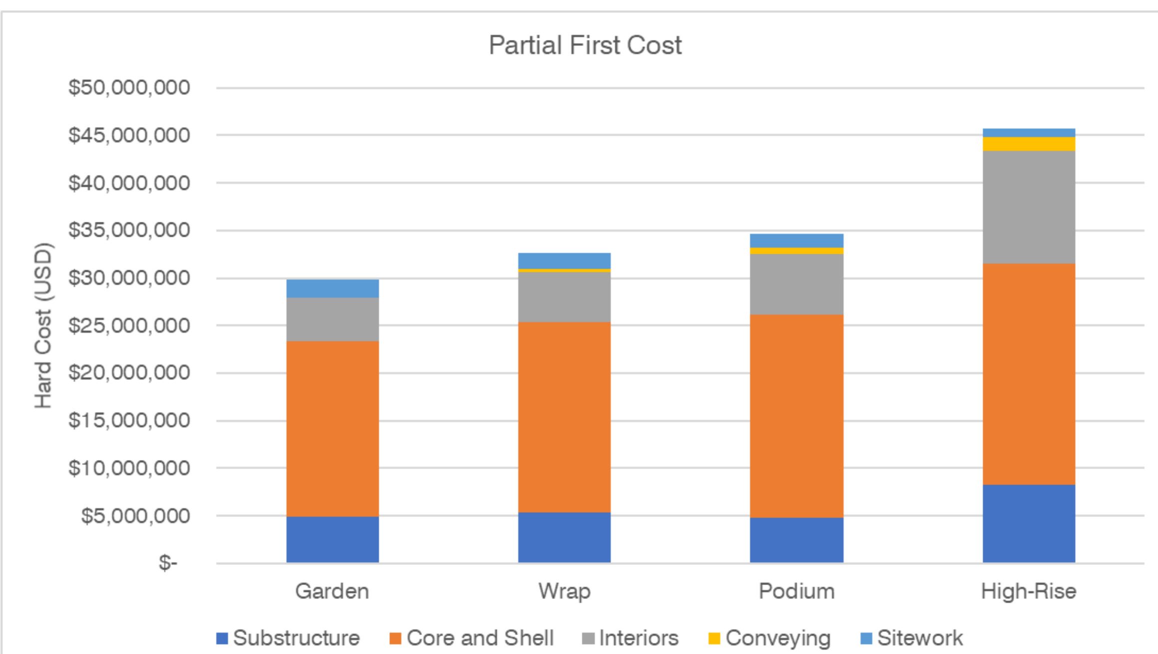

Figure 5: First Cost Estimate for each Typology

Of the solutions evaluated, costs ranged from a high of $45,744,396 (for the high-rise building) to a low of $29,853,399 (for the garden apartments). Cost was roughly proportional to density, with higher densities necessitating more of the expensive non-combustible construction and lower densities being achievable with more comparatively inexpensive light-wood framing. Expenses are divided into five categories, roughly mirroring five of the categories utilized in Uniformat.

The first category, substructure, consisted of foundation and slab-on-grade expenses. While this was notably higher for the deeper foundations of the high-rise, expenses across the other three types were somewhat similar. While larger bearing capacities and thus larger footings were required as density increased, the footprint of the foundation decreased, rendering foundation expense for the overall projects similar.

The second category, Core and Shell, represented the largest overall share of the project budget in each of the four typologies. Costs were generally higher for non-combustible steel and concrete elements than for light-wood framed elements. This was also true for the third category, interiors, which included mostly partitions, interior doors, and ceiling framing. While these costs were similar across the primarily wood-framed projects, the use of light-gauge steel framing in the high-rise represented a significant cost increase.

The fourth category was conveying, which included only the cost elevators, as other conveying (e.g. trash chutes) was not considered. Thus, the costs are generally proportional with the number and type of elevators. The walk-up garden apartments had no elevator expenses. The mid-rise solutions had fewer elevators, and the high-rise had the greatest number of elevators and the greatest number of stops. Of note, the use of hydraulic elevators in the wrap type represented a significant cost savings.

Finally, site work was considered. This consisted mostly of hardscape, site lighting, and landscaping, and included only work outsize of the building footprint. Unsurprisingly given this narrow definition, these costs scaled proportionally with the area of the site, with lower costs for higher-densities.

3.2 Evaluating Embodied Carbon

Embodied carbon was evaluated using quality take-offs for assemblies included using the Athena Impact Estimator tool. As with first cost, mechanical, electrical, fire protection, interior finishes, fixtures, and casework were not considered. Lifecycle emissions were calculated based on national averages for a sixty-year lifespan. Scopes including A-D were included, with the operationally component of Scope B evaluated separately in the following section. The results are snow in *Figure 6*.

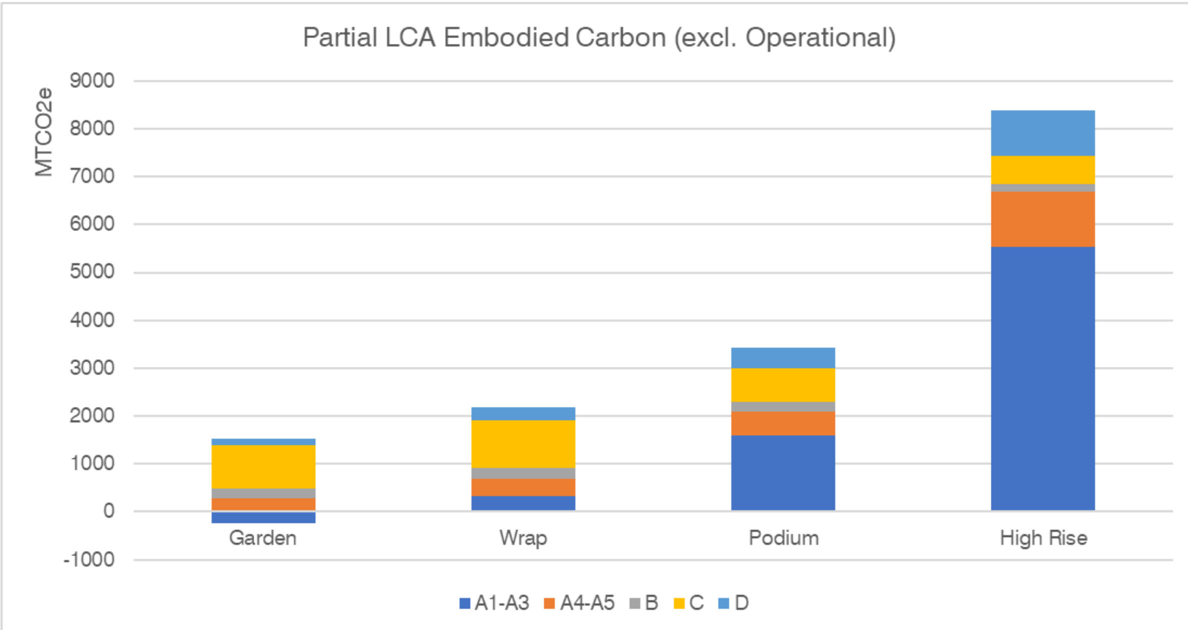

Figure 6: Lifecycle Embodied Carbon for each Typology

Immediately evident is a substantially higher different between types than was observed in first costs. The poorest performing solution, the high-rise, contributed to carbon dioxide equivalent emissions over five times as much overall. The lifecycle was divided into four parts, which are discussed below.

First, Production State (A1-A3) represented so called "cradle to gate" emissions associated with the harvesting of raw materials and their manufacturing into building components. Of note, the wood-framed solutions were very performative along this access due to biogenic carbon implications of sequestering carbon within the wood itself. As more and more concrete and steel are included with denser typologies, this effect fades, with enormous carbon implications for the only solution which utilizes no wood-framing, the high-rise.

Construction State (A4-A5) accounts for transportation of materials to site and initial erection of the building. Of note, no specific site was selected and national averages were utilized, which renders the A4 transportation scope of questionable validity. Once again, construction utilizing heavy materials (steel and concrete) represented the greatest share of construction emissions, likely due to the more robust systems required to transport and place these materials.

Use Stage (B) accounted for a relatively small share of overall emissions, likely because carbon associated with operations was considered elsewhere. Thus, this category represents on maintenance, repair, replacement, and refurbishment over the building's lifecycle. Interestingly, the high rise, with its more durable non-combustible systems, was the most performative along this axis, although the overall quantities are small.

End of Life Stage (C), was generally higher among wood-framed solutions, as the biogenic carbon sequestered during the A-phase now is released back to the atmosphere. Comparatively, Beyond Building Life Stage (D) had the opposite quality, with the relatively high energy costs associated with recycling and re-use of steel and concrete clearly evident.

3.2 Evaluating Operational Carbon

Unlike the other three categories considered, it was not possible to use a national average for considering operational energy performance, as this quality will be dependent on climate and very location specific. Thus, Des Moines, Iowa was selected as location due to its centrality and its location in ASHRAE Climate Zone 4, which includes relatively high heating and cooling degree days. Zone 4 was also utilized to specify construction assemblies, with R-20 wall cavity insulation, for example, being provided in concert with the requirements of the IECC.

Also in-line with the IECC proscriptions for the "base case" models used in the trade-off and whole-building compliance paths[xi], the mechanical system selected was a packaged terminal air conditioner with a natural gas fired hot-water heating coil. Since no ancillary uses (e.g. amenities, circulation) were greater than 20,000 square feet, no secondary systems were designed. Parking was assumed to be unconditioned, although lighting loads were included. Energy associated with certain high-rise exigencies, such as conveying, domestic water booster pumps, etc. was outside the scope of this project. Likewise, while in practice the domestic hot water heating systems utilized would likely vary between typologies, this was not considered.

A Grasshopper visual programming algorithm based on the Honeybee and Ladybug plug-ins was utilized. This consequently relied on the use of Open Studio and the Energy Plus simulation engine, which are both "under the hood" components in Honeybee. The result of the operational energy evaluation is provided in *Figure 7*.

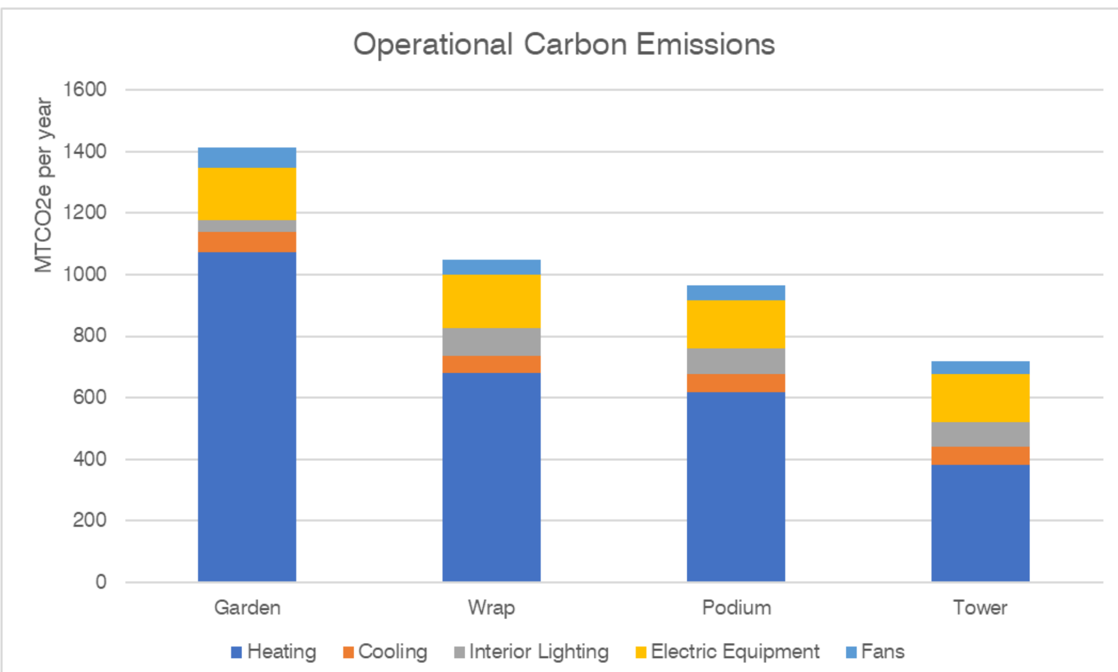

Figure 7: Yearly Operational Carbon Emissions by End Use

The information was disaggregated across five end uses, of which heating was by far the largest component in each model. Given the subject buildings are likely envelope dominated, it is unsurprising that heating energy is associated with form compactness, with the solutions with the highest surface-to-volume ratio requiring the most energy to condition. Less clear is the role of cooling energy, which his more constant across forms, suggesting this may be more affected by interior loads that were consistent across type, rather than envelope loads.

Electric equipment use was relatively constant, as this is based on floor area and does not vary with envelope conditions.

Of note, the carbon emission are based on 2024 energy mix for Des Moines and do not account for future electrification or inclusion of additional renewables in the electric grid over time.

Clearly, a trade-off exists between the higher embodied energy of the more compact forms and the lower operational energy. Of note, when considering a sixty-year lifecycle, embodied carbon represented a share of total carbon emission which varied from 1.50% in the garden typology to 16.27% in the high-rise typology. While the later figure is more consistent with findings of other studies[xii], the numbers for wood frame are notable lower. This suggests that our method (i.e. omitting MEPFP, omitting finishes) has a greater reduction effect on operational than embodied carbon.

4.0 Conclusion

In an effort to compare new hybrid light-wood-framed multifamily typologies, we constructed models of typical buildings for four typologies: garden apartments; wrap/donut buildings; podium buildings, and high-rise buildings. We evaluated these models along three axes, for construction first hard cost, operational carbon emissions, and embodied/lifecycle carbon emissions.

Our findings suggest that these new typologies lie somewhere between the low first cost and embodied energy commitment of garden apartments and the high first cost and embodied energy commitment of high-rise apartments. Conversely, operational energy use, which represented the vast majority of lifecycle carbon emissions, was found to be roughly proportional to building compactness, with higher density solutions performing better. These findings are subject to the following caveats.

4.1 Limitations

Our analysis was not exhaustive and, as a matter of practical necessity, omitted many factors which may be germane. When considering first cost, it was necessary to omit any site-specific costs (e.g. entitlements, land costs) due to the non-location-specific nature of the project. It is likely that land-cost and restrictions enumerated via the entitlements process would vary substantially between projects, and may be determinative of the type of project constructed. It is also likely, in reality, systems between types would vary substantially, with the curtain-wall envelope and hydronic fan-coil system typical to taller buildings being different than the opaque infill typical of smaller typologies. While it was necessary to hold these factors constant to achieve a fair comparison, future researchers may consider cost and embodied energy as typically built.

Other factors in affecting first cost, embodied energy, and operational energy would require a more complete building design. Just a single example of many, taller buildings typically have domestic water booster pumps which may not be included in low-rise buildings. Sizing and evaluating the costs of these elements would require complete engineering, which future studies may more exhaustively explore.

Evaluating first cost and embodied energy on a per-assembly basis, while convenient from a calculation standpoint, also likely misses several cost and embodied factors which would vary between buildings. For example, constructing a partition wall ten floors in the air have additional costs (e.g. tower crane, skip-hoist) in both economic and embodied carbon terms which are not adequately accounted for here.

Likewise, while we constructed models based on our understanding of best practices, the performance along all axes is likely to vary with design decisions made in the model, including orientation, floor plate depth, etc. A more thorough survey would involve a sensitively analysis which could adequately measure how findings would be changed with changes to the prototype buildings.

Our examination was based on national averages (for cost and embodied energy) and one central location (for operational energy). While this has the advantage of broadening applicability, it also has the drawback of harming validity. More completed analysis would likely include regional variation in each of the three axes, as well as regional variation common to the models themselves.

4.2 Further Research

While our efforts represented something of a pilot test, future analysis should engage with questions of location-specific construction methods, materials, costs, and climates. Future research should also include a greater range of building systems specific to the typologies, including vertical circulation, domestic water heating, and interior finishes and fixtures.

For operational energy, future analysis should subject buildings to a more diverse set of climates and locations, as results may vary in, for example, a hotter climate where less insulation is required by code. Operational variables should also be expanded to include a variety of design decisions.

For embodied energy, consideration of location is also critical. Wood typologies may be more attractive in, say, the Pacific Northwest, where softwood lumber is more plentiful and nearby. Embodied energy analysis may also consider a more realistic set of building variation. For example, a high-rise may use a curtain wall or at least larger punched openings.

Finally, for first cost, variations in land cost and regionally specific costs should be explored. Costs should also reflect the longer construction timeline of denser solutions and attendant financial implications on construction financing and occupancy phasing.

More granular analysis of energy performance may also consider the transportation implications of building at different typologies. While the embodied energy of denser buildings is higher, this may to some degree be offset by lower transportation energy afforded by living at higher densities.

4.3 Recommendations for Stakeholders

While findings are subject to the qualifications stated above, some useful information for project stakeholders can be inferred. First, light-wood hybrid typologies, be they low-or-midrise, appear to have lower embodied energy than non-combustible taller construction. Authorities having jurisdiction should endeavor to expand the degree to which this construction is permitted, at least to the extent that life-safety is not affected by such changes.

Solutions with lower surface-to-volume ratios were also more performative along operational axes, suggesting that regardless of which typology is selected, designers should endeavor to use the deepest floor plates possible, minimizing envelope area per unit floor area.

Finally, even when taller buildings are necessitated by circumstances, developers and designers should explore the use of wood as a means carbon sequestration. A growing body of research points to the suitability of mass-timber and mass-plywood construction in taller solutions, which would eliminate some of the embodied drawbacks typically associated with light-wood construction.

Considered cumulatively, we have identified a base-case performance for the building typologies identified along the axes identified. Yet, this is intended to be a starting point for evaluation. The greatest promise in this investigation is not in identifying base performance, but optimizing performance and allocation of multifamily units between typologies. For now, this analysis remains incomplete.

Notes:

[i] EIA, "2020 Residential Energy Consumption Survey: Energy Consumptiona and Expenditures Table" (U.S. Energy Information Administration, 2015), https://www.eia.gov/consumption/residential/.

ii Tudor Scolca, "Where Multifamily Deliveries Will Break Records in 2024 and Beyond," Multi-Housing News, August 27, 2024, https://www.multihousingnews.com/where-multifamily-deliveries-will-break-records-in-2024-beyond/.

iii Core Logic, Marshall & Swift Valuation Service (Place of publication not identified: Marshall & Swift/Boeckh, 2020).

iv Rachel Azoff, "Multifamily Developers Turn to Wood-Frame Construction to Cut Costs," Multifamily Executive, July 1, 2009, https://www.multifamilyexecutive.com/design-development/construction/multifamily-developers-turn-to-wood-frame-construction-to-cut-costs_o.

v Terry Malone, "5-over-2 Podium Design," Structure Magazine, January 2017, https://www.structuremag.org/?p=10934.

vi Patrick Sisson, "Why Do All New Apartment Buildings Look the Same?," Curbed (blog), December 4, 2018, https://archive.curbed.com/2018/12/4/18125536/real-estate-modern-apartment-architecture.

vii Oren Mandelbaum, "Designing Transit-Oriented District Station Areas for Pedestrian Activity: Learning from Dallas, TX," 2023.

viii Adrian Smith + Gordon Gill Architecture, RESIDENSITY: A Carbon Analysis of Residential Typologies, First Edition (Novato, California: ORO Editions, 2022).

ix Christopher Drew, Katrina Fernandez-Nova, and Keara Fanning, "The Environmental Impact of Tall vs. Small: A Comparitive Study," International Journal of High-Rise Buildings 4, no. 2 (June 2015): 109–16.

x The Gordian Group, Inc., RSMeans Data from Gordian (Rockland, MA, 2020), rsmeansonline.com.

xi International Code Council, "2021 International Energy Conservation Code," accessed January 26, 2025, https://codes.iccsafe.org/content/IECC2021P1.

xii T. Ibn-Mohammed et al., "Operational vs. Embodied Emissions in Buildings—A Review of Current Trends," Energy and Buildings 66 (November 2013): 232–45, https://doi.org/10.1016/j.enbuild.2013.07.026.