Chapter 4

Conceptual Design Examples

4.1 INTRODUCTION

The optimal cost-revenue conceptual designs of four office buildings are presented in this chapter to illustrate the applicability, efficiency and practicality of the computer-based multi-criteria optimization capability developed by this study. Table 4.1 lists the parameter values governing the design of the four example buildings, which differ only in their geographic locations and, thus, in their land costs, lease and tax rates and material costs. It is assumed that locations with lower land cost and tax rates have lower lease rates (e.g., see Table 4.1, where the rangers of low to high annual lease rates correspond to building that have poor to good quality of office space-see Figure 3.3).

Example 1 concerns the design of an office building that has U.S. national average unit costs for concrete and steel construction, and which is located in a city having expensive land and high lease and tax rates. Example 2 modifies the Example 1 design case by locating the building in another city that has cheaper land and lower lease and tax rates. Example 3 considers yet another design case by locating the building in a city that has a relatively high cost for steel construction compared to that for concrete construction. Conversely, Example 4 differs from Example 3 in that the building is located in a city that has a high cost for concrete construction compared to that for steel construction.

Table 4.1: Governing Parameters for Design Examples

Design Parameter	Design Example 1	2	3	4
Location Information				
Land Unit Cost ($\$/m^2$)	12000	1000	12000	12000
Annual Lease Rates ($\$/m^2/yr$)	300-540	100-360	300-540	300-540
Maintenance (%capital cost)	2	2	2	2
Taxes (%building value)	5	2	5	5
Mortgage Rate (%)	10	10	10	10
Inflation Rate (%)	3	3	3	3
Cost Location Factors ($/USavg$)				
Structural steel	1	1	1	0.88
Concrete	1	1	0.74	1
Reinforcement	1	1	0.79	1
Forming	1	1	0.51	1
Cladding	1	1	1	1
Windows	1	1	1	1
Roofing	1	1	1	1
Finishing	1	1	1	1
Electrical	1	1	1	1
Mechanical	1	1	1	1
Elevators	1	1	1	1
Geographical & Orientation Information				
Latitude (Degree North)	40	40	40	40
Angle of building with East (Degree)	0	0	0	0
Environmental Information				
Clear Sky Percentage (%)	75	75	75	75
Hot Day Relative Humidity (%)	80	80	80	80
Cold Day Relative Humidity (%)	50	50	50	50
Inside Temperature (C^0)	22	22	22	22
Ave. Max. Outside Temp.(C^0)	31	31	31	31
Ave. Min. Outside Temp.(C^0)	-20	-20	-20	-20
Hot Day Temp. Range (C^0)	10	10	10	10
Cold Day Temp. Range (C^0)	10	10	10	10
Load Information				
Applied Dead Load (kN/m^2)	1.45	1.45	1.45	1.45
Gravity Live Load (kN/m^2)	2.80	2.80	2.80	2.80
Wind Load Pressure (kPa)	0.48	0.48	0.48	0.48
Seismic Load	N/A	N/A	N/A	N/A
Building Limits				
Max Footprint Width (m)	70	70	70	70
Max Footprint Length (m)	70	70	70	70
Max. Building Height (m)	300	300	300	300
Min. Lease Office Space (m^2)	60,000	60,000	60,000	60,000
Fixed Core/ Footprint Area (%)	20	20	20	20
Min. Core/ Perimeter Distance(m)	7	7	7	7
Min. Aspect Ratio	0.5	0.5	0.5	0.5
Max. Slenderness Ratio	9	9	9	9
Min. Floor/ Ceiling Clearance (m)	3	3	3	3

From Table 4.1, note that: all four buildings have 60,000m ^{2} of lease office space; the cost of maintenance work required to maintain and upkeep the building components is taken as 2% of the capital cost of HVAC, elevator and lighting systems, finishes, facade and roofing; the annual cost of property taxes is taken as 5% of the building value for Examples 1, 3 and 4, while it is taken as 2% for Example 2; the unit dead load accounts for the weight of wall partitions, ceilings and fixtures, floor finishing, plumbing and ducting (NBCC 1990); the unit live load accounts for the weight of office equipment, furnishings and occupants (NBCC 1990); all gravity dead and live loads are applied as uniformly distributed loads over the entire building footprint area at each story level, including the roof; lateral wind loads are calculated as a function of the building surface area and the specified wind pressure; both direct and suction wind loading are applied at each story level as equivalent concentrated loads; seismic loading is assumed to be not applicable for the building designs; and that all four design examples are controlled by the same building limitations, i.e.,

- Maximum building footprint width a_{max} = 70m
- Maximum building footprint length b_{max} = 70m
- Maximum building height H_{max} = 300m
- Minimum lease office space A_{req} = 60,000m^2
- Core area $Percentage(D_a \times D_b)$ = 20% of footprint area
- Minimum distance between building core and perimeter CPD_{min} = 7m
- Minimum building aspect ratio $(D_a / D_b)_{Lower}$ = 0.5 (assuming $D_a < D_b$)
- Maximum building slenderness ratio $(H / D_a)^{Upper}$ = 9.0 (assuming $D_a < D_b$)

These limitations restrict the buildings to have from 15 to 80 stories which, for practical design purposes, limits the structure types that may be considered for their conceptual design to the ten choices listed in Table 3.1 (also listed are the possible choices for the floors, cladding, windows, window ratio, number of bays and corresponding span distances-see Section 3.2.3). It is assumed that each building is in a downtown city location, with zero property clearance, such that the land cost is defined by the area of the building footprint.

The basic unit costs listed in Table 4.2 are U.S. national averages (Mean's Manuals 1999). It is noted that (see Chapter 3 for full details): the finishing unit cost accounts for the cost of painting, carpets and other trim for the building in addition to the cost of the main partitions; the electrical unit cost accounts for the cost of florescent lighting required to provide an illumination level of 20 Watts/m^2, in addition to the cost of associated wiring, outlets and transformers (Mean's Manuals 1999); the HVAC unit costs account for the cost of boilers, chillers, ducts and fan rooms required to accommodate the heating and cooling loads imposed on the building by occupants, lighting, equipment, ventilation, thermal conduction through exterior walls, and thermal conduction and solar radiation through windows (the ventilation, conduction and radiation loads are defined by the clear sky, humidity and temperature factors listed in Table 4.1, and by the thermal and shading coefficients for the types of cladding and windows for the building listed in Table 3.A.8); the plumbing unit cost accounts for the cost of toilets and service fixtures, in addition to the cost of plumbing required for the HVAC and fire extinguisher systems; the energy unit cost accounts for the cost of the energy consumed by office equipment and by the HVAC, elevator and lighting systems.

The computer-based computational procedure outlined in Figure 3.4, and described in Section 3.2.6, is applied to find Pareto-optimal conceptual designs for the four example office buildings that minimize capital and operating costs and maximize revenue income. To facilitate application of the multi-criteria genetic algorithm (MGA), the primary design variable values listed in Table 3.1 are represented by their binary equivalents given in Table 3.2, and the following genetic operators and data are adopted:

- Genetic population size = 1000 conceptual designs
- Reproduction = Weighted roulette wheel simulation
- Crossover = Two-point, with 100% probability
- Mutation = Single-bit, with initial probability of 5% that gradually decreases to 2% as the genetic search progresses so as to avoid significant random changes in the genetic pool at the final stages of the search.

Convergence at the final stages of the genetic search is taken to occur when 1) the number of Pareto-optimal designs, 2) the optimum values for the three objective criteria and 3) the design located at the knee of the Pareto surface (i.e., the design closest to the point in the Pareto space having the optimum values of the three objective criteria as its coordinates) all remain relatively unchanged for 20 consecutive generations. For each of the four building examples, the MGA is run for three different initial genetic populations and the Pareto designs found at convergence of the three runs are combined together to form the corresponding overall Pareto-optimal design set.

Table 4.2: Basic Building Costs

Materials, Components and Energy	**Cost**
Steel Cost ($/ton)	2039
Concrete Cost ($/m^3)	143
Reinforcement Cost ($/ton)	1400
Formwork Cost ($/m^2)	45
Finishing Cost($/m^2)	130
Roofing Cost($/m^2)	63
Plumbing Cost ($/m^2)	45
HVAC Boiler Cost ($/kW)	225
HVAC Chillers Cost ($/kW)	715
Electrical System Cost ($/m^2)	121
Energy Cost Elec. ($/mWhr)	100
Energy Cost Gas. ($/mWhr)	40

All unit costs are US national averages and include account for the costs of materials, shipping, unloading, accessories and installation.

4.2 DESIGN EXAMPLE 1

One purpose of this example is to study the effect of relatively expensive land cost on the design of an office building. Upon applying the multi-criteria optimization procedure (Figure 3.4), the three different runs of the MGA converged after 147, 149 and 140 generations to find 779, 766 and 752 Pareto designs, respectively. The Pareto designs found from the three runs were then combined together to form the overall set of 815 Pareto-optimal conceptual designs for the office building indicated (by grey dots) in Figure 4.1. From among all Pareto designs for the building, the minimum and maximum lease office spaces are 60,000 m^2 and 61,740 m^2, respectively, a difference of less than 3%. The shortest Pareto design is 19 stories high and has a plan footprint that measures 70m x 60m. The tallest Pareto design is 52 stories high with a 50m x 30m plan footprint.

The 815 individual Pareto-optimal designs plotted in Figure 4.1 collectively form a three-dimensional (3-D) convex surface that represents the Pareto trade-off relationships between the objective criteria to minimize capital and operating costs and maximize income revenue (i.e., minimize 1/income revenue). Figure 4.1 is not very informative as it is, but its wealth of information becomes immediately evident when computer color filtering is used to highlight zones of the Pareto surface occupied by different architectural and structural parameters for the building. These Pareto zones identify cost-revenue trends and relationships in a graphical format that can be readily understood by architects and design engineers, as shown in the following.

The computer-generated color filtering of the 3-D Pareto surface shown in Figures 4.2, 4.3, 4.4, and 4.5 highlights the Pareto zones corresponding to the different structural types, number of stories, bay areas, and window ratios possible for the building. These colour graphs yield the interesting observation that the Pareto zones are grouped with little or no overlap (which is a direct consequence of the cost-revenue interplay occurring between the different types of Pareto-optimal conceptual designs for the building). Figures 4.2 and 4.3 indicate that among the ten structural types considered for the design (Table 3.1), only eight are suitable for this example; namely, steel frame with bracing & outriggers and concrete rigid frame with shear walls, which are the tallest Pareto-optimal designs at about 35 to 52 stories, followed by steel frame/ rigid frame with concrete shear walls at 28 to 36 stories, steel frame/ rigid frame with bracing at 21 to 29 stories, unbraced steel rigid frame at 19 to 23 stories, and unbraced concrete rigid frame at 20 stories and below. Figures 4.6, 4.7, 4.8 and 4.9 present 2-D plots of Figures 4.2, 4.3, 4.4 and 4.5, respectively, and readily provide the following cost-revenue information concerning the Pareto-optimal conceptual designs for the building.

1. Steel frame with bracing & outriggers and concrete rigid frame & shear wall structural systems result in the lowest capital cost for the building compared to that for braced steel frames and unbraced steel and concrete frames (Figures 4.2, and 4.6a,b). The reason for this is that the land cost is relatively expensive and is a major component of the overall capital cost for the building. From among the eight structural types found in the Pareto-optimal set for this example, steel frame with bracing & outriggers and concrete rigid frame & shear walls, for US national average construction costs, are the most capital cost-effective for taller buildings which, for a fixed total amount of floor space, have smaller footprint dimensions and therefore require the purchase of the least amount of land.

2. Unbraced concrete rigid frame structural systems result in the highest capital cost for the building compared to that for unbraced and braced steel frames, steel frame with shear walls, concrete rigid frame with shear walls and steel frame with bracing & outriggers (Figures 4.2 and 4.6a,b). The reason for this is that the land cost is relatively expensive and is a major component of the overall capital cost for the building. From among the eight Pareto-optimal structural types found for this example, unbraced concrete rigid frame construction is the most capital cost-effective for shorter buildings which, for a fixed total amount of floor space, have larger footprint dimensions and therefore require the purchase of the most amount of land.

3. For fixed annual revenue income, taller buildings have higher annual operating cost (Figures 4.3 and 4.7c). The reason for this is that two important components of the annual operating cost for a building are the cost of the energy required to operate the HVAC system and the maintenance cost for the HVAC system, elevators and facade. For a fixed total amount of floor space, the surface on the perimeter of the building increases as the building height increases, which increases the HVAC energy cost. In the same manner, the maintenance costs of the HVAC system, elevators and facade increase when the number of stories increases due to the increase in construction costs for these building components.

4. For fixed annual operating cost, shorter buildings have higher annual income revenue (i.e., smaller 1/ income revenue -Figure 4.7c). The reason for this is that larger bay

areas increase the flexibility of floor space usage, which increases the lease rate for office space (see Figure 3.3) and, hence, the annual income revenue for the building. For a fixed total amount of floor space, as the building height decreases the foot print area of the buildings increases, which allows for larger bay areas.

5. Buildings with smaller bay areas have smaller capital cost (Figures 4.8a,b). The reason for this is that a major component of the capital cost of the building superstructure is the cost of the floor system, which decreases as the bay area decreases.

6. Buildings with larger bays areas have bigger annual income revenue (i.e., smaller 1/revenue income -Figure 4.8c). The reason for this is that larger bay areas increase the flexibility of floor space usage, which increases the lease rate for office space and, hence, the annual income revenue for the building.

7. Buildings with lower window ratios have smaller annual operating cost (Figures 4.9a,c). The reason for this is that a major component of the annual operating cost for a building is the cost of the energy required to operate the HVAC system which, for any given structural system and number of stories, decreases as the window ratio decreases.

8. Buildings with higher window ratios have bigger annual income revenue (i.e., smaller 1/ income revenue -Figure 4.9b). The reason for this is that larger window

ratios increase the amount of natural daylight experienced indoors, which increases the space quality and the lease rate for office space (see Figure 3.3) and, hence, the annual income revenue for the building.

Depending on architectural-structural and cost-revenue preferences for the building, the foregoing information can serve to guide the design team's selection of a small subset of the Pareto-optimal conceptual designs for further detailed consideration. One such selection is those designs that first become profitable over time taking into account occupancy levels and life-cycle costing. To that end, for annual revenue income calculated over time for the occupancy levels listed in Table 3.3, for annual operating cost calculated for the entire building area regardless of the occupancy level, and assuming that the entire capital cost of the building is mortgaged, Eq. (3.12) is applied using the annual mortgage and inflation rates given in Table 4.1 to find the subset of designs identified in Figure 4.10 as first becoming profitable in the 11th year after completion of building construction. Observe from Figures 4.2, 4.3 and 4.10 that all of the profitable designs are taller buildings in the range of 32 to 36 stories having steel frame/ rigid frame with concrete shear wall and concrete rigid frame with shear wall structural systems. The design team may select the first profitable design indicated (by a black dot) in Figure 4.10 and shown in Figure 4.11 as the basis for further preliminary/final design calculations. It is noted that the design shown is Figure 4.11 need not be the only design so considered, but that any of the first-profitable designs indicated in Figure 4.10 may be studied further, as may be any other Pareto-optimal design in Figure 4.10 depending on the preference of the design team.

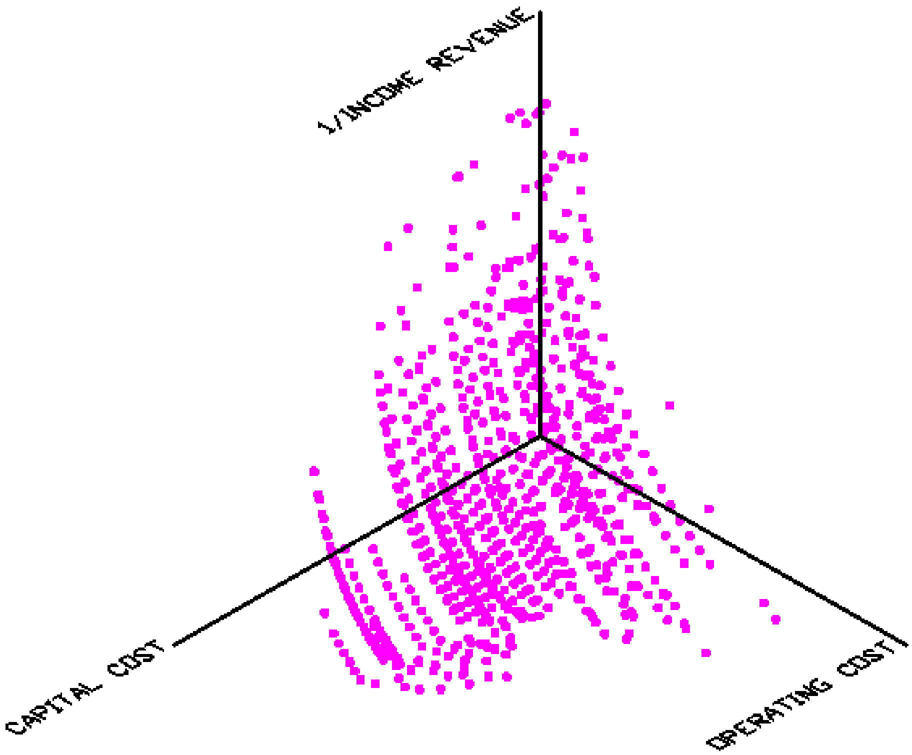

Figure 4.1: Example 1- 3D Pareto Design Space

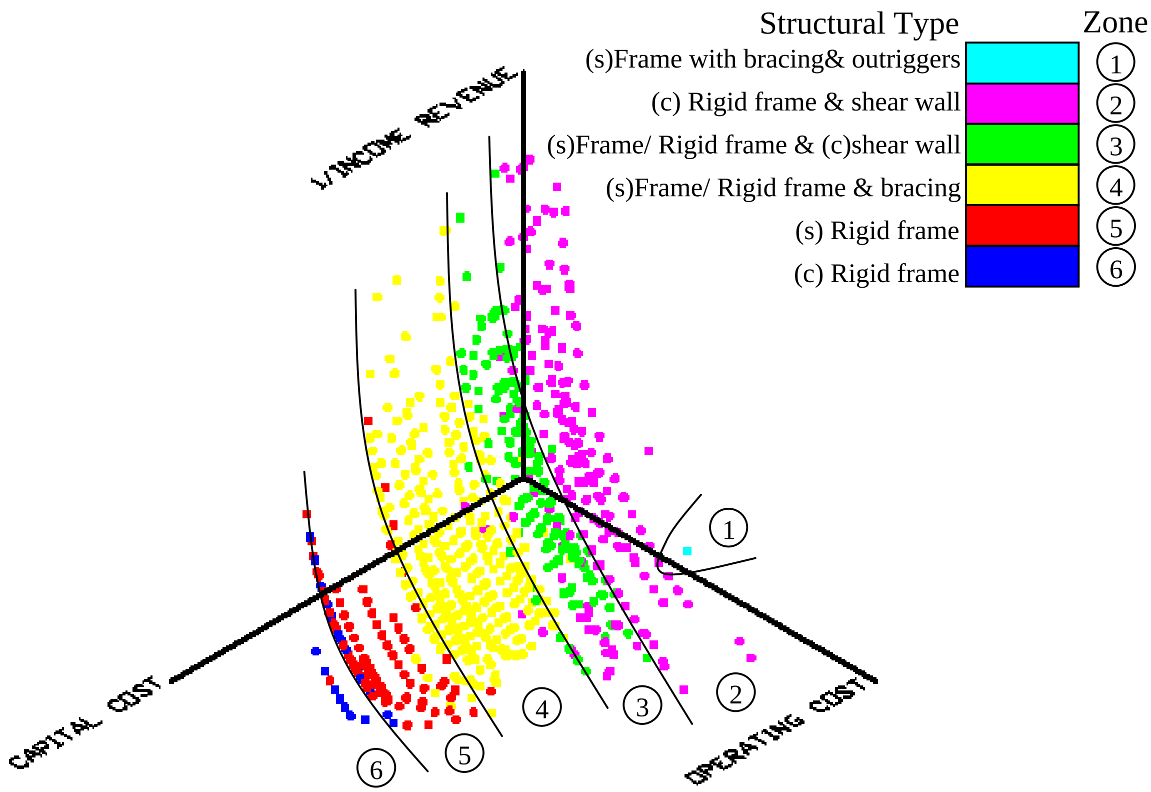

Figure 4.2: Example 1- Structural Type Pareto Zones

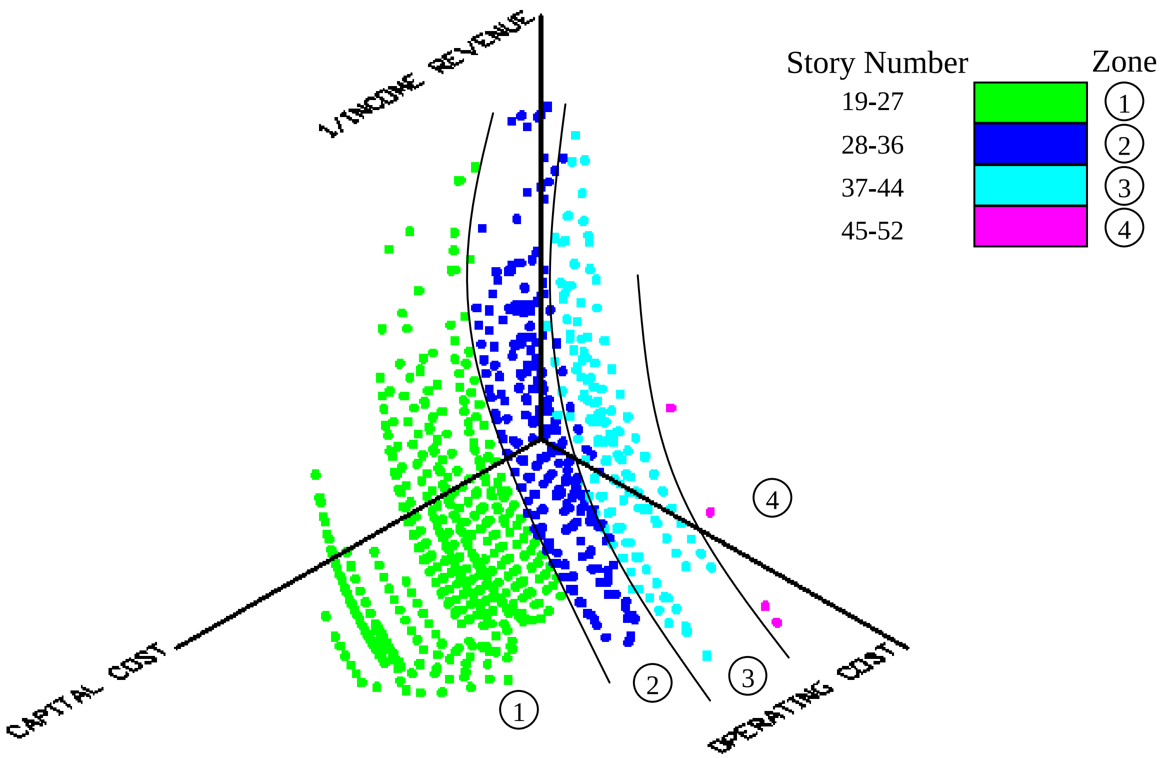

Figure 4.3: Example 1- Story Number Pareto Zones

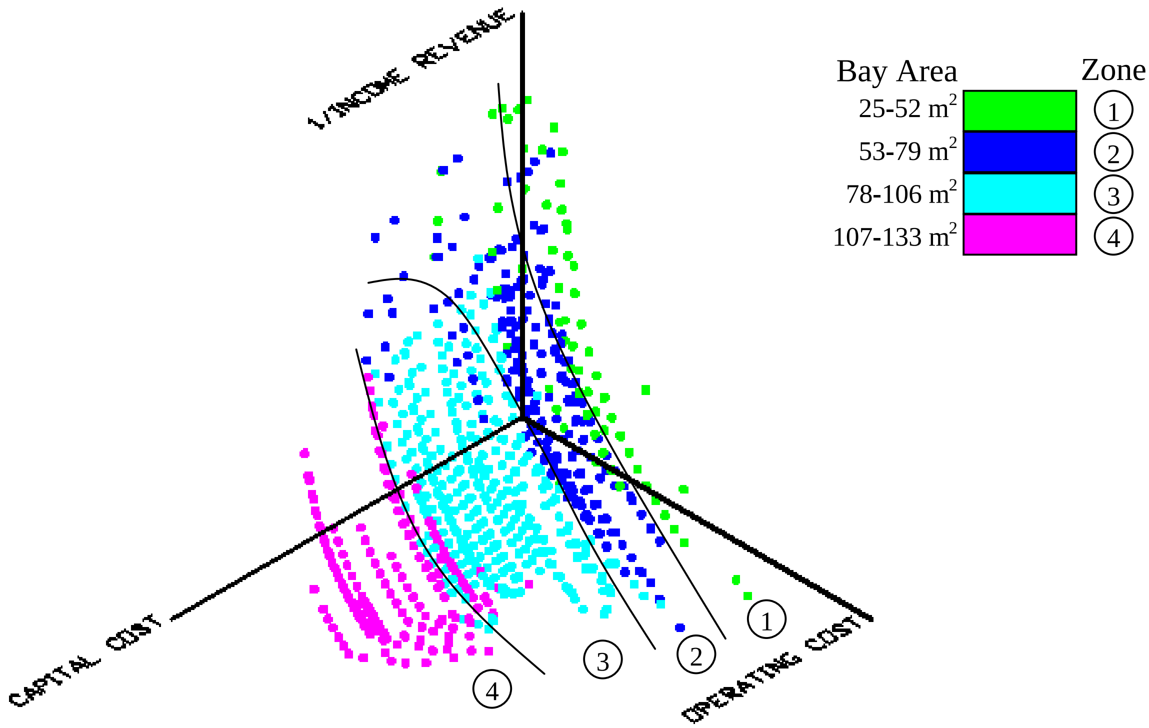

Figure 4.4: Example 1- Bay Area Pareto Zones

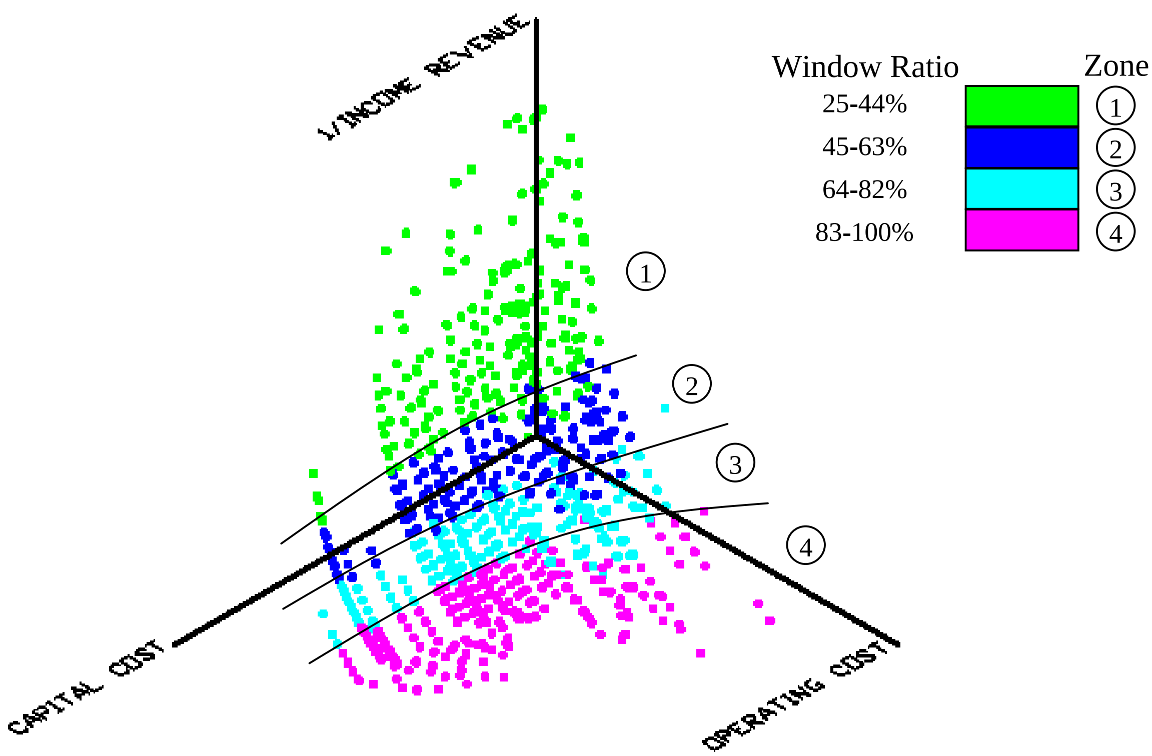

Figure 4.5: Example 1- Window Ratio Pareto Zones

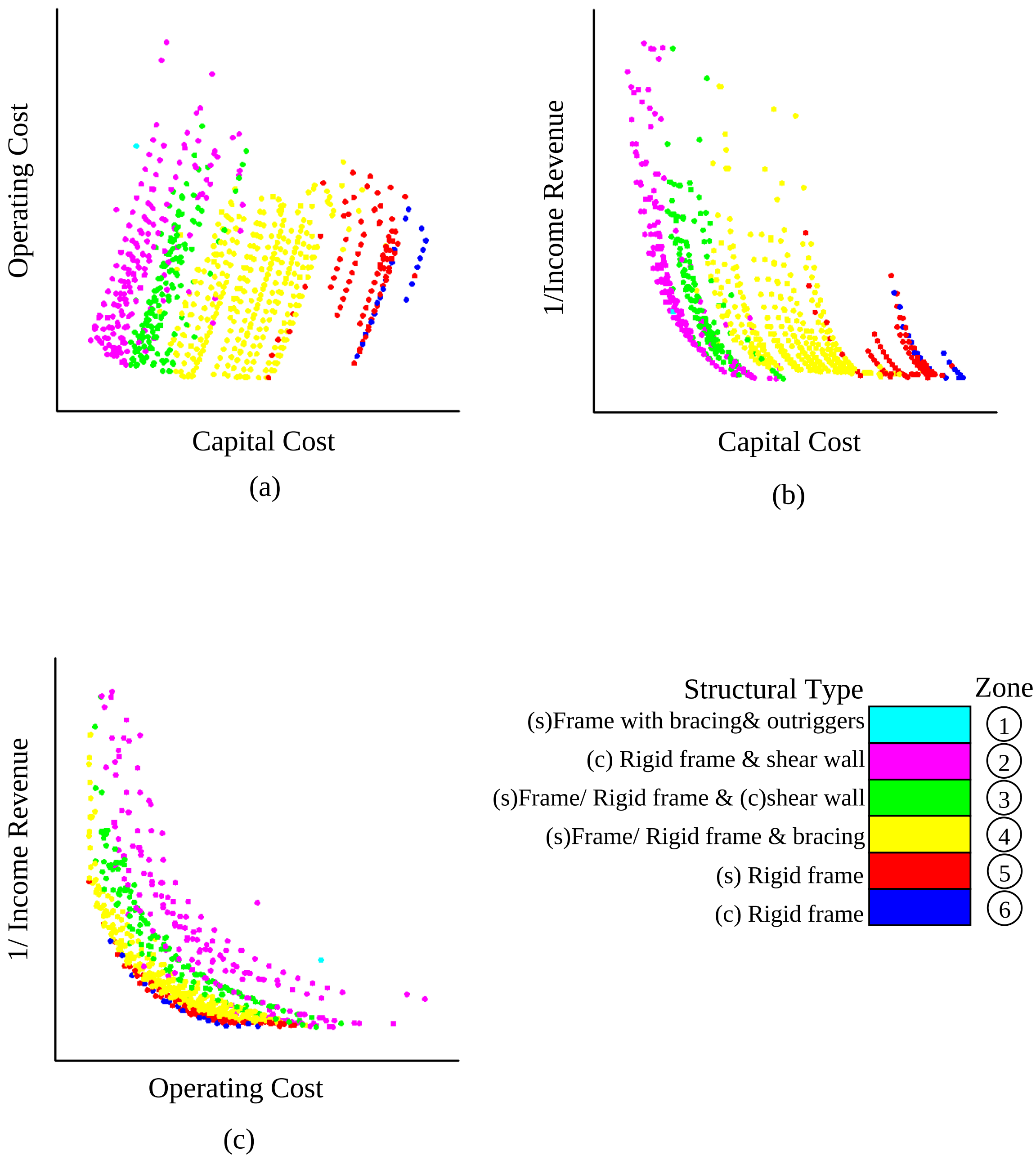

Figure 4.6: Example 1- 2D Plots of Structural Types Pareto Zones

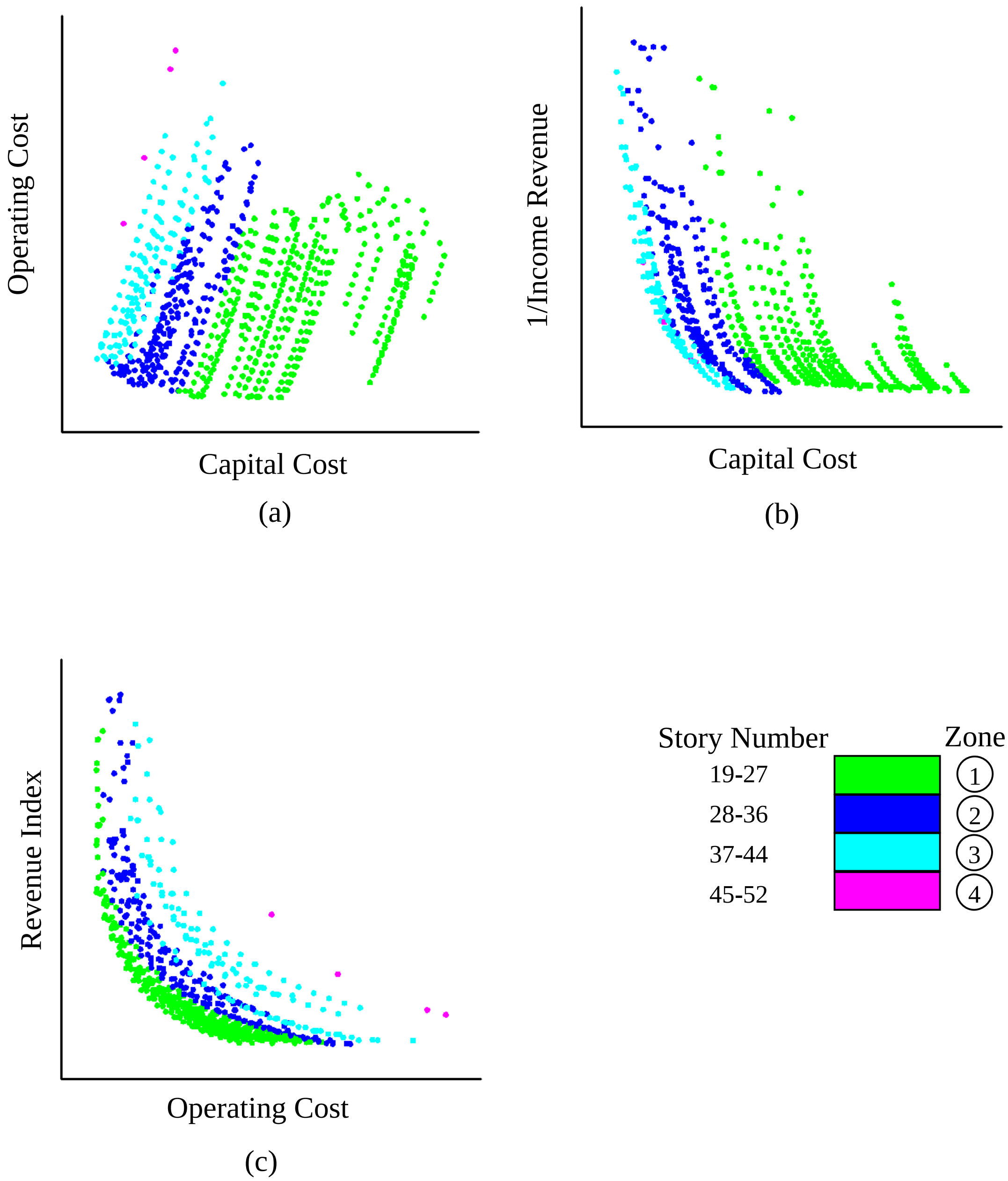

Figure 4.7: Example 1- 2D Plots of Story Number Pareto Zones

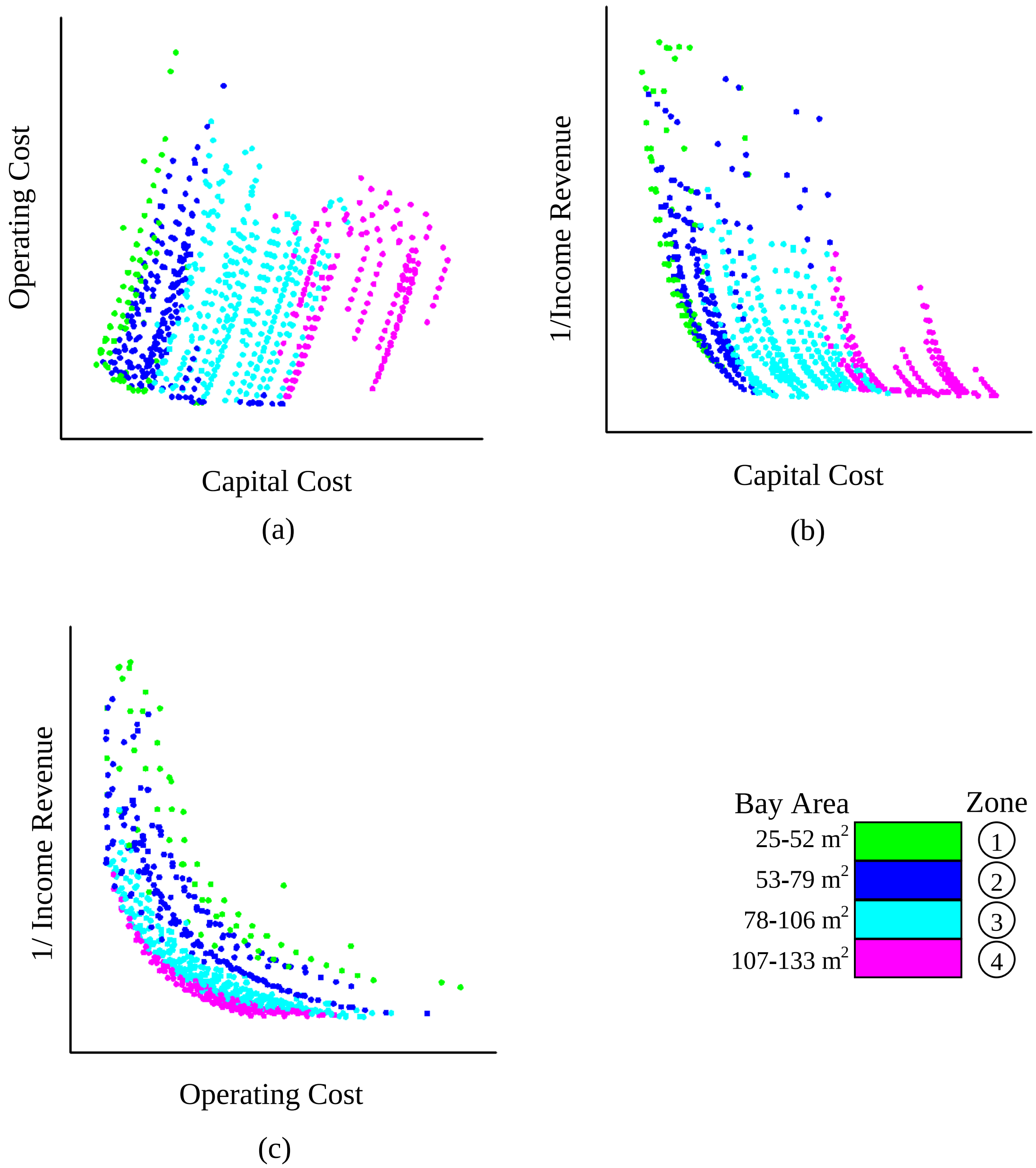

Figure 4.8: Example 1- 2D Plots of Bay Area Pareto Zones

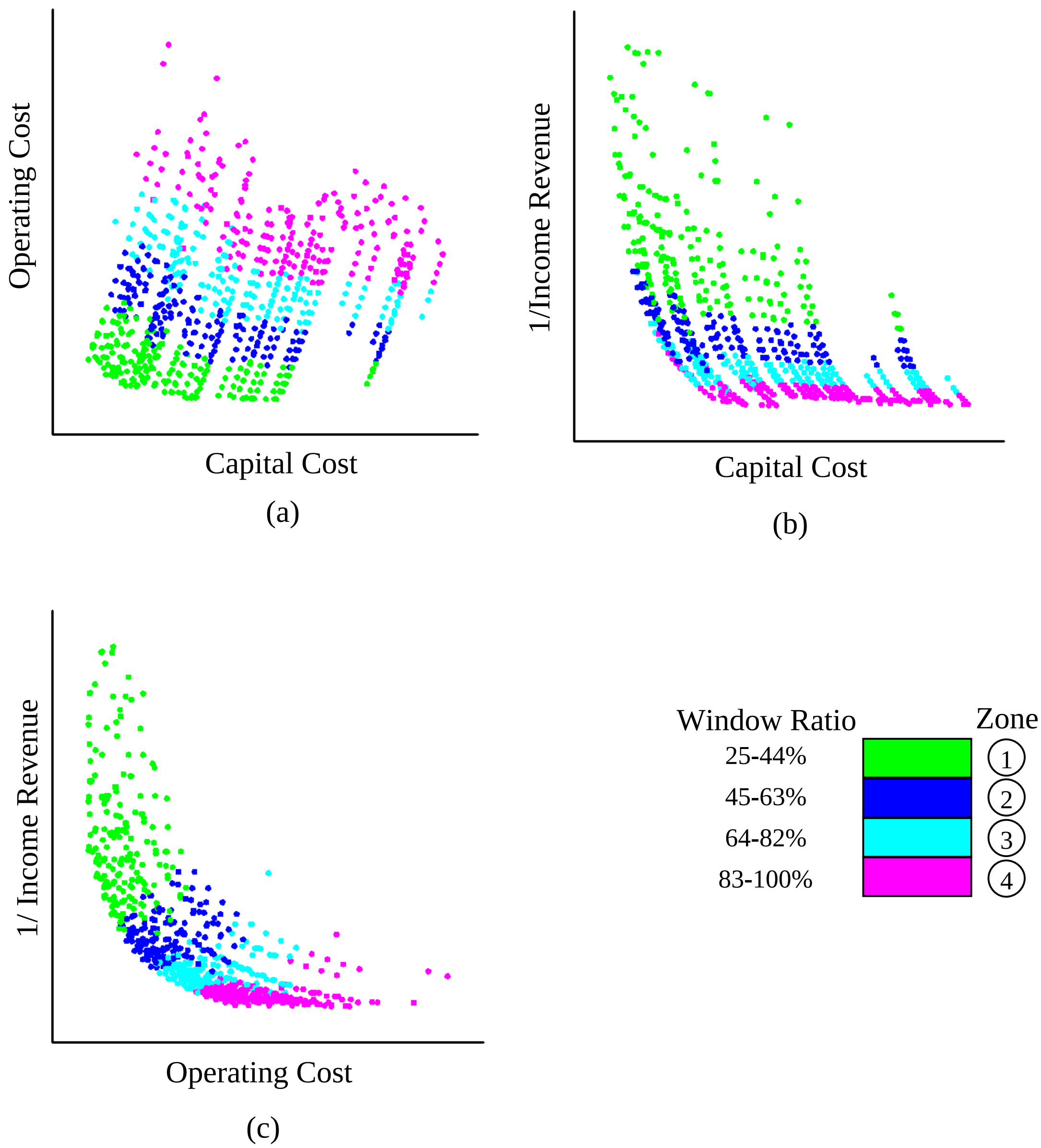

Figure 4.9: Example 1- 2D Plots of Window Ratio Pareto Zones

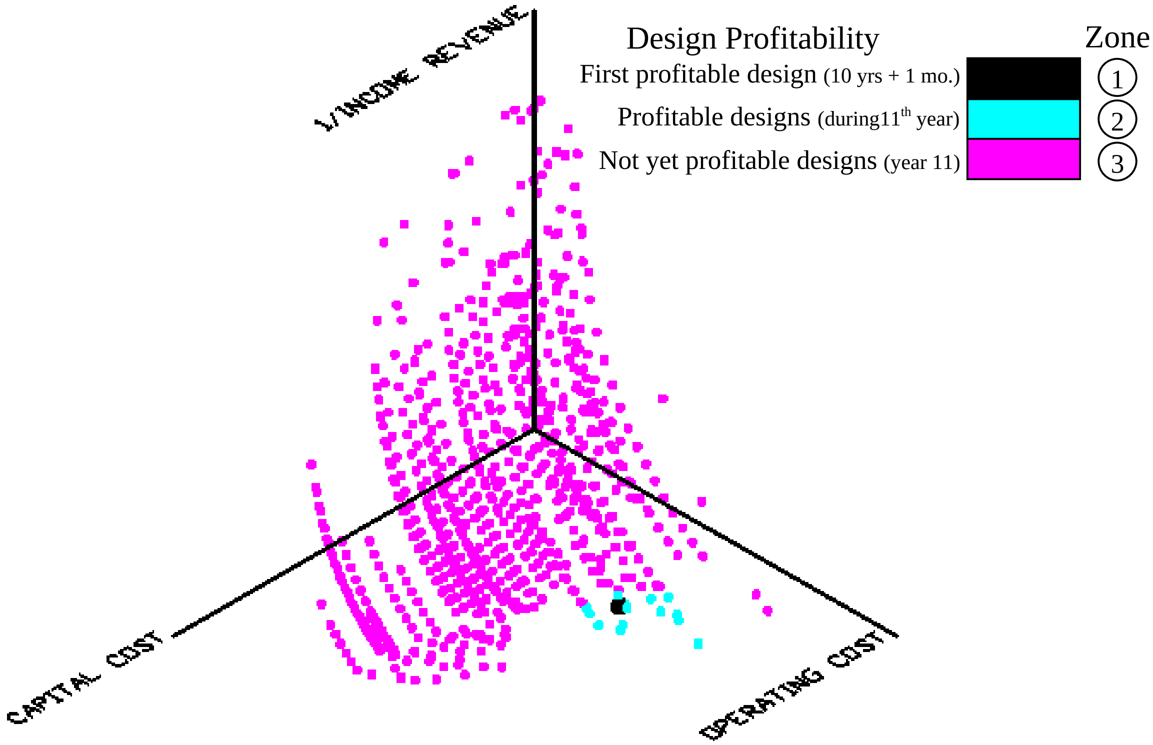

Figure 4.10: Example 1- Design Profitability

Structure: Concrete frame and shear wall
Floor: Two way flat plate
Total Number of floors: 32
Number of rental floors: 31
Number of mechanical floors: 1
Foot print: 68m x 36m
Height: 122m
Bay area: 8.5m x 12m
Core: 38.37m x 12.76m
Floor area: 60710m^2
Window Ratio: 100%
Window : Insulated HA
Cladding: Metal siding panel
Elevators: 21
Stairs: 2
Stair width: 1.1m
Capital cost: $ 107.98 M
Annual operating cost: $ 8.91 M
Annual revenue Income: $ 29.98 M
Lease rate: 497 $/m^2

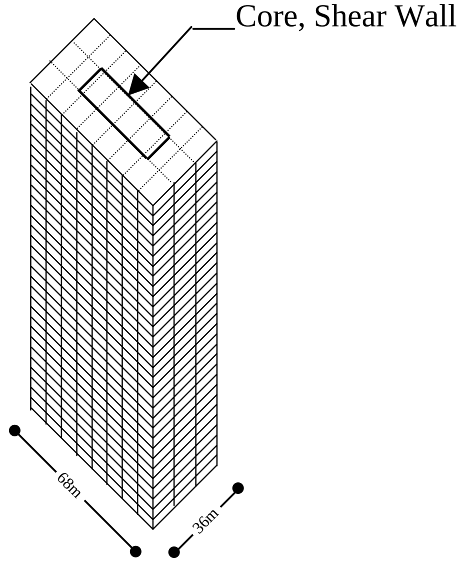

Figure 4.11: Example 1-The First Profitable Design

4.3 DESIGN EXAMPLE 2

This example is the same as Example 1 except that it has smaller land unit cost and office space lease rates in addition to lower tax rates (see Table 4.1), and serves to illustrate that the solution of the conceptual design problem can be quite sensitive to changes in the parameter values prescribed for office buildings. Here, the three different runs of the MGA converged after 147, 151 and 162 generations to find 99, 115 and 122 Pareto designs, respectively, which were then combined together to form the overall set of 139 Pareto-optimal conceptual designs for the office building indicated (by grey dots) in Figures 4.12. From among all Pareto designs for the building, the minimum and maximum lease office spaces are 60,000m^2 and 61,180m^2, respectively, a difference of less than 2%. The shortest Pareto design is 17 stories high with a 69m x 68m plan footprint, while the tallest Pareto design is only 26 stories high with a 60m x 50m footprint.

The computer colour filtering of the 3-D Pareto surface shown in Figures 4.13 4.14, 4.15 and 4.16 highlights the Pareto zones corresponding to the different structural types, number of stories, bay areas and window ratios possible for the building. A comparison of these four colour graphs with those in Figures 4.2, 4.3, 4.4 and 4.5 indicates that the results for this example are significantly different than those for Example 1. Figure 4.13 indicates that steel frame/ rigid frame & bracing, unbraced steel rigid frame and concrete rigid frame are the only viable structural systems for the building; i.e., contrary to Figure 4.2 for Example 1, there are no Pareto-optimal conceptual designs of the building for this example that have a concrete rigid frame with shear wall, steel frame/ rigid frame with shear wall or steel frame with bracing & outriggers structural system. Moreover, Figures 4.13, 4.14 4.17a and 4.18a together indicate that shorter buildings with an unbraced concrete frame structural system have the lowest capital cost; i.e., contrary to that indicated in Figures 4.2 and 4.3 for Example 1, taller buildings with braced and unbraced steel frame structural systems have higher capital cost for this example. The main reason for this reversal is that the cheaper land for this example favours shorter buildings with larger plan foot print areas; i.e., contrary to Example 1, the capital cost trade-off between buying more land or constructing taller structural systems is such that it is cheaper to buy more land (in fact, as implied by Figure 4.14, structural systems that are beyond 26 stories for this example result in uneconomical buildings in the sense that they are not Pareto-optimal because shorter building designs exist that simultaneously have lower capital and operating costs and higher income revenue than they do).

On the other hand, the trends concerning bay areas and window ratios for this example, Figures 4.15 and 4.16, were found to be essentially the same as those previously observed in Figures 4.4 and 4.5 for Example 1. For example, similar to that observed in Figure 4.4, buildings with smaller bay areas have smaller capital cost (because the cost of the floor system decreases as the bay area decreases) and, similar to that observed in Figure 4.5 and 4.9a, buildings with lower window ratios have smaller annual operating cost (because the energy cost for the HVAC system decreases as the window ratio decreases).

For the same occupancy levels and mortgage and inflation rates as previously noted for Example 1, Eq. (3.12) was applied for this example to identify a subset of Pareto designs that first become profitable in the 12th year after completion of building construction, as shown in Figure 4.19. Contrary to Example 1, it was found that all of the profitable designs were shorter buildings with unbraced concrete rigid frame structural systems (see Figures 4.13, 4.14 and 4.19). The building design to first become profitable for this example is shown in Figure 4.20. The lower capital cost, operating cost and revenue income for this design compared that for the first profitable design for Example 1 (Figure 4.11) are the result of the lower land unit cost, lower tax rate and lower lease rate for this example. Note from Figures 4.14 and 4.19 that all of the profitable designs for this example are in the range of only 18 to 20 stories high as compared to the taller profitable buildings for Example 1 that range from 28 to 36 stories. It is interesting to note that the building design that first becomes profitable for this example is only 19 stories high (Figure 4.20), while that for Example 1 is 32 stories tall (Figure 4.11). The design team may select the first profitable design indicated (by a black dot) in Figure 4.19 and shown in Figure 4.20 as the basis for further preliminary/final design calculations. In fact, any number of the Pareto designs in Figure 4.12 could be selected for further study. If profitability is a motivating factor, however, the design team may be advised to concentrate on the first-profitable designs indicated in Figure 4.19, all of which have a concrete frame structural system that is 19 to 20 stories high.

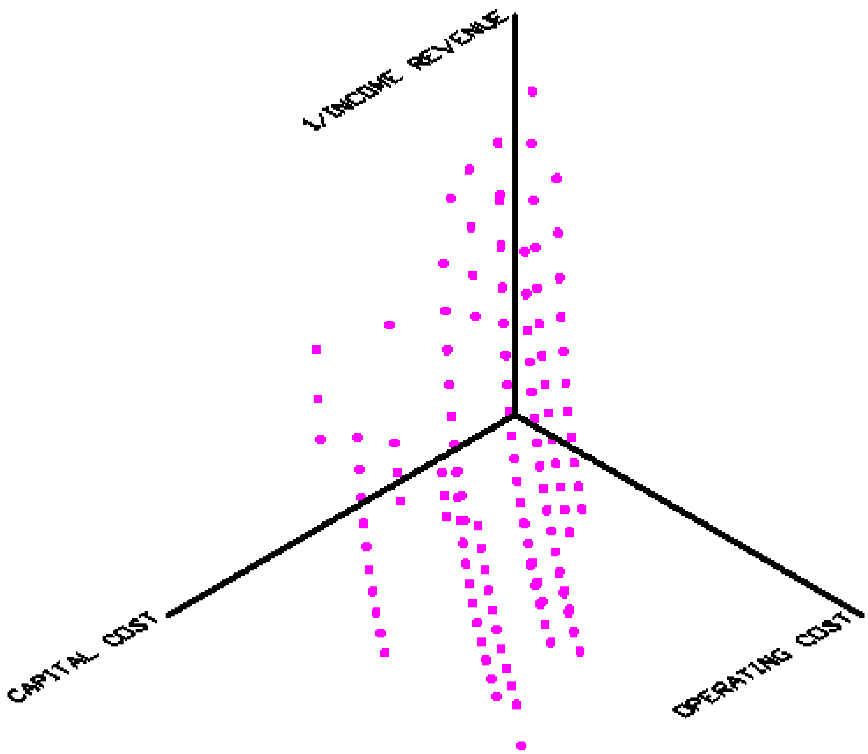

Figure 4.12: Example 2- 3D Pareto Design Space

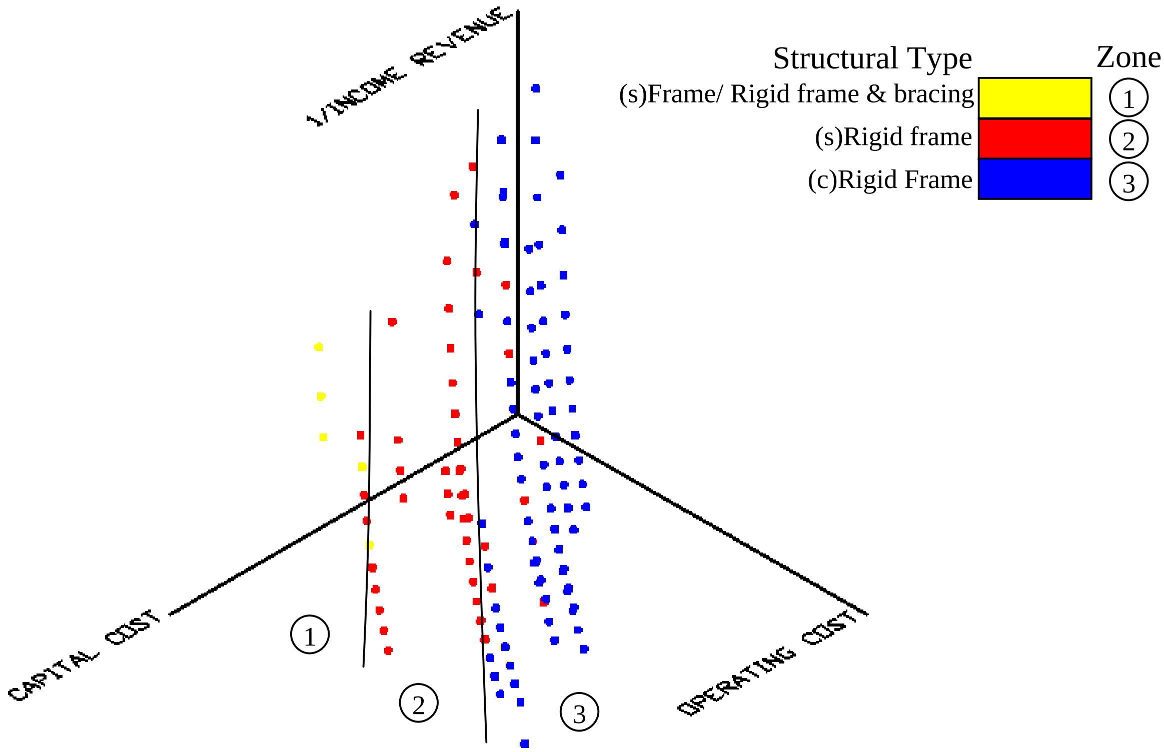

Figure 4.13: Example 2- Structural Type Pareto Zones

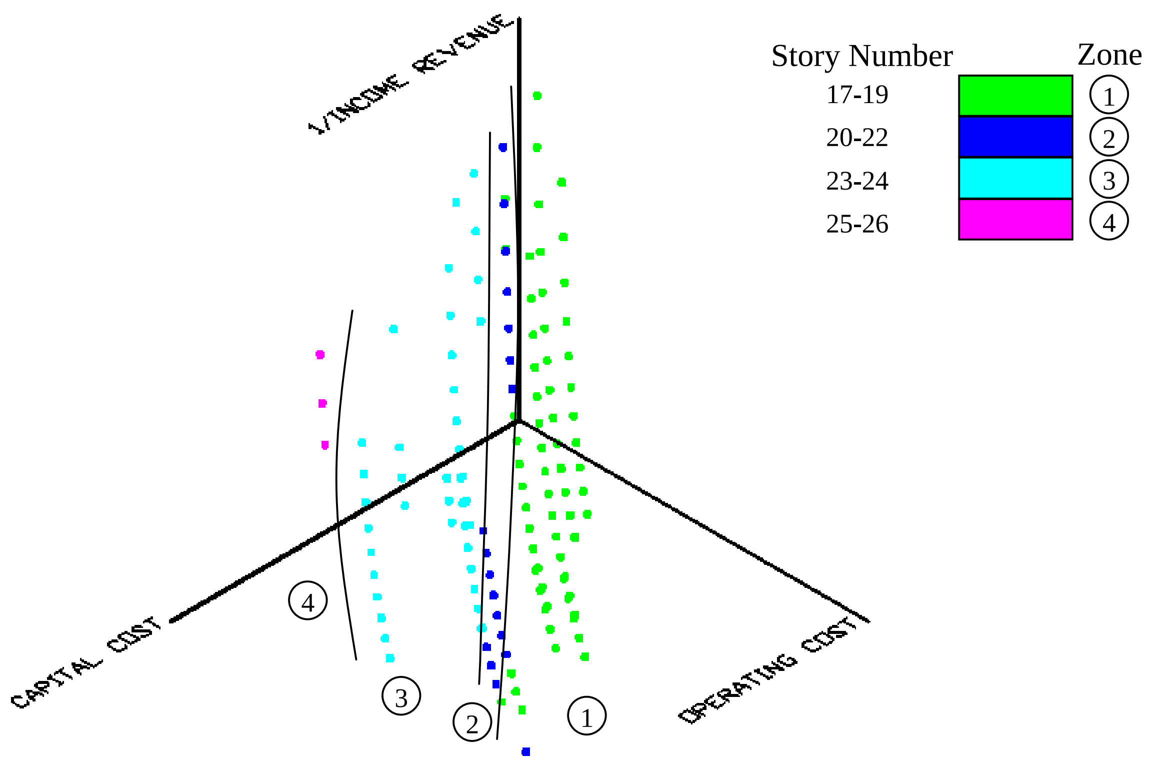

Figure 4.14: Example 2- Story Number Pareto Zones

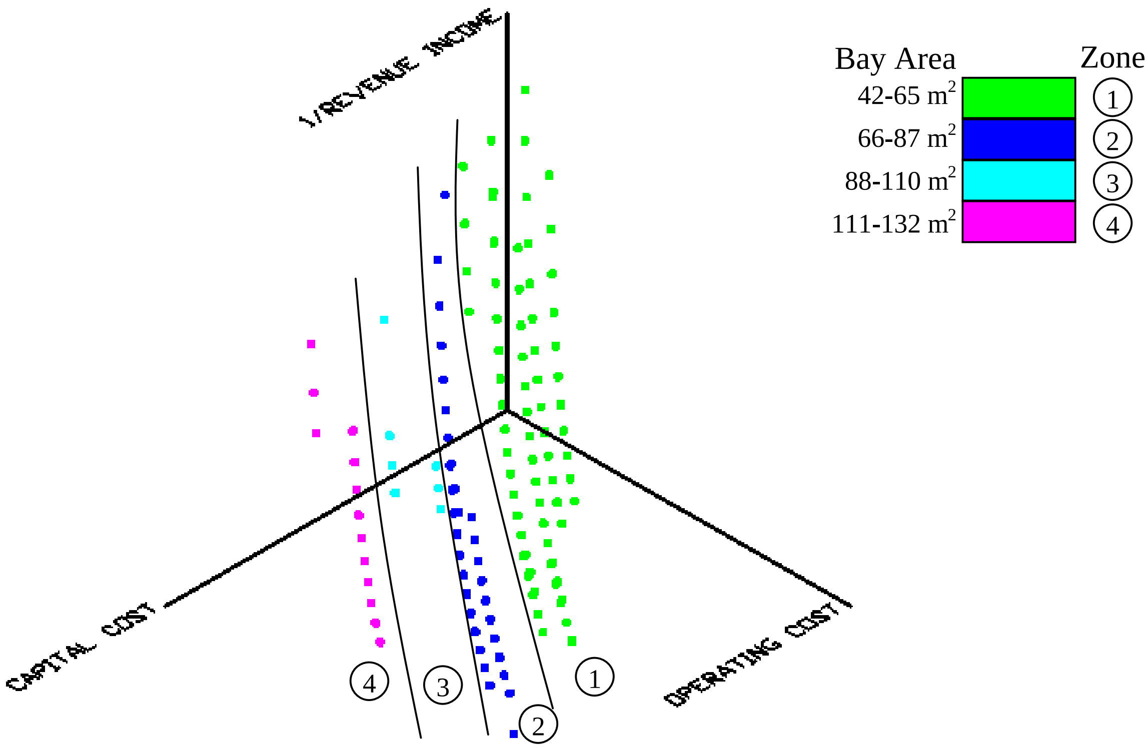

Figure 4.15: Example 2- Bay Area Pareto Zones

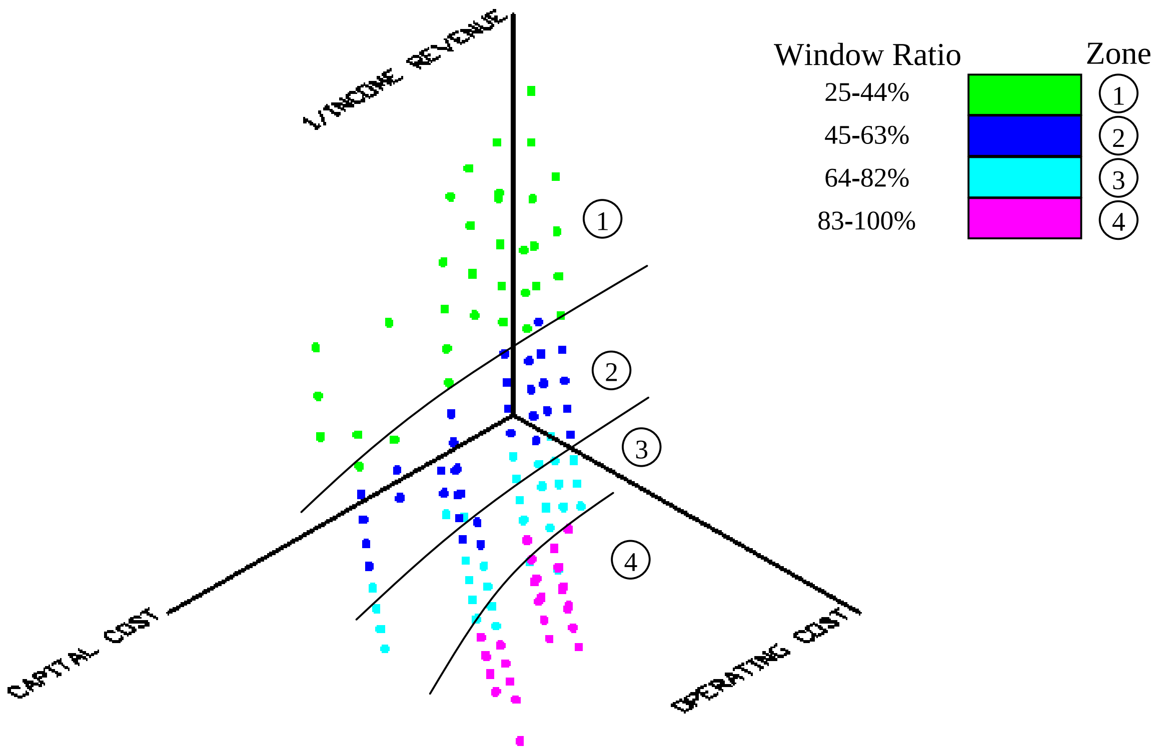

Figure 4.16: Example 2- Window Ratio Pareto Zones

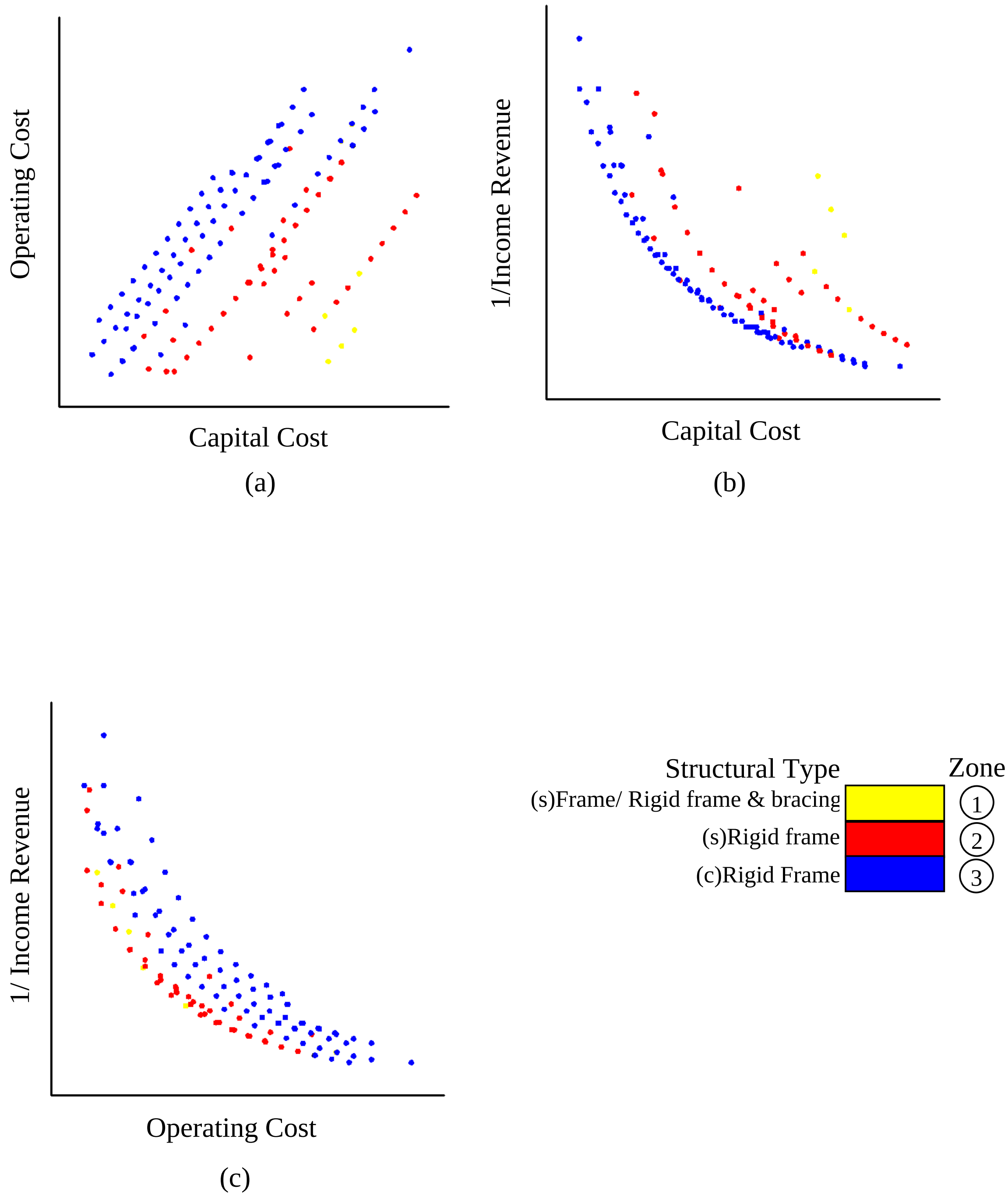

Figure 4.17: Example 2- 2D Plots of Structural Systems Pareto Zones

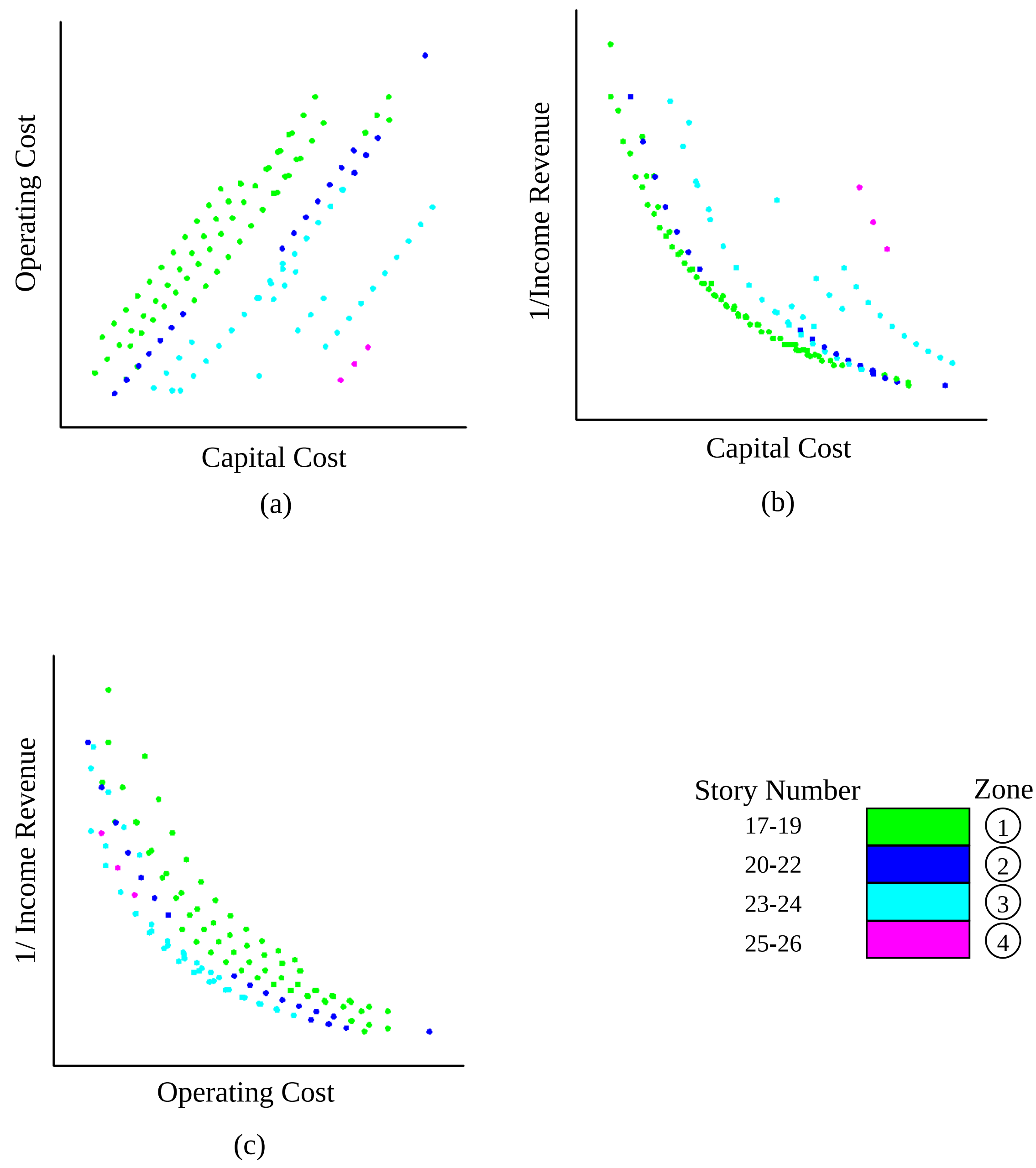

Figure 4.18: Example 2- 2D Plots of Story Number Pareto Zones

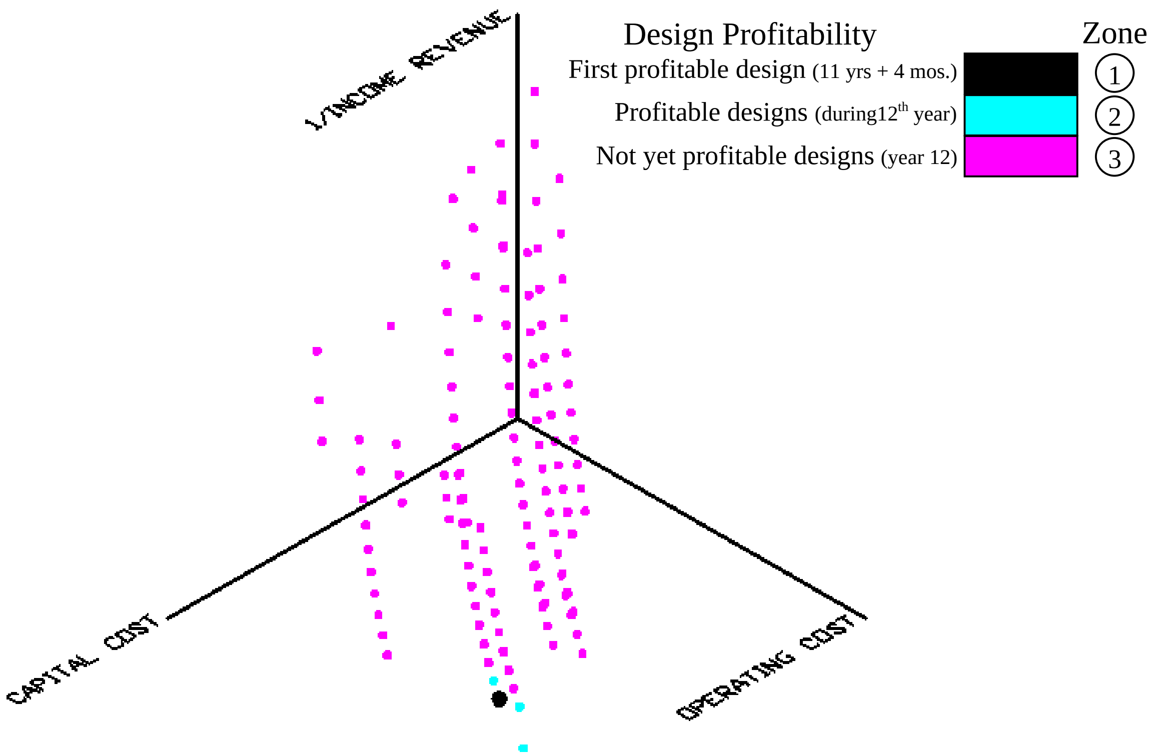

Figure 4.19: Example 2- Design Profitability

Structure: Concrete frame
Floor: Two way beam and slab
Total Number of floors:19
Number of rental floors: 18
Number of mechanical floors: 1
Foot print: 70m x 60m
Height: 76m
Bay area: 7m x 12m
Core: 56m x 15m
Floor area: 60480m^2
Window Ratio: 100%
Window : Insulated HA
Cladding: Metal Siding
Elevators: 21
Stairs:2
Stair width: 1.675m
Capital cost: $ 75.3M
Annual operating cost: $5.2M
Annual revenue Income: $18.6M
Lease rate: $308/m^2

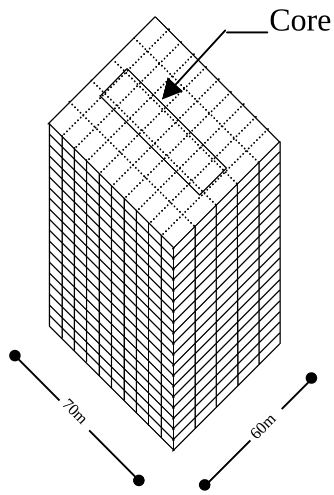

Figure 4.20: Example 2-The First Profitable Design.

4.4 DESIGN EXAMPLES 3 & 4

One purpose of these two examples is to study the effect that different material costs have on the Pareto optimality of building designs. The examples are the same as Example 1, except that Example 3 has (on average) 33% lower unit cost for reinforced concrete construction and Example 4 has 13% lower unit cost for structural steel construction compared to the corresponding U.S. national average unit costs prevailing for Example 1 (see Table 4.2). For Example 3, the three different runs of the MGA converged after 134, 142 and 136 generations to find 675, 652 and 635 Pareto designs, respectively, which combine together to form an overall Pareto set of 804 designs (see Figures 4.21 and 4.22). For Example 4, the three different runs of the MGA converged after 154, 136 and 147 generations to find 820, 852 and 817 Pareto designs, which combine together to form an overall Pareto set of 958 designs (see Figures 4.23 and 4.24).

The conceptual design results presented in Figure 4.21 for Example 3 indicate that concrete rigid frame and concrete rigid frame with shear wall are the only viable structural systems for the building when the cost of reinforced concrete construction is low compared to that for structural steel construction; i.e., contrary to Figure 4.2 for Example 1, there are no Pareto-optimal conceptual designs of the building for Example 3 that have braced or unbraced steel frame structural systems. Furthermore, the Pareto-optimal concrete structural systems for Example 3 are economically viable for a broader range of story numbers than they were for Example 1 (see Figures 4.2, 4.3,4.21 and 4.22). Conversely, the results presented in Figure 4.23 indicate that unbraced and laterally braced steel frames are the only viable structural systems for the building when the cost of structural steel construction is low compared to that for reinforced concrete construction; i.e., contrary to Figure 4.2 for Example 1 and Figure 4.21 for Example 3, there are no Pareto-optimal conceptual designs of the building for Example 4 that have braced or unbraced concrete frame structural systems. Note also that the Pareto-optimal steel structural systems for Example 4 are economically viable for a broader range of story numbers than they were for Example 1 (see Figures 4.2, 4.3,4.23 and 4.24). These two examples serve to illustrate that material costs can have a significant influence on the solution of the conceptual design problem for office buildings.

4.5 COMPUTER EXECUTION TIMES

All results for the foregoing examples were found using a Pentium II computer with 266 MHz CPU (Civil Engineering Department, University of Waterloo). Examples 1, 3 and 4 each took about 14.5 hrs for three runs of the multi-criteria genetic algorithm (MGA), or an average of 4.75 hrs per run, while Example 2 required an average of 4.33 hrs per MGA run. Basically, the computer execution time for a MGA run is comprised of the time required to calculate the values of the cost-revenue objective criteria for all designs in the genetic population, plus the time required to carry out the operations of the MGA. Since the population size is constant for all four examples, the processing time to find the values of the objective criteria for each generation of the genetic search is constant among the four examples. The lower processing time for Example 2 can be attributed to the lower number of Pareto designs found for this example compared to that for Examples 1, 3 and 4.

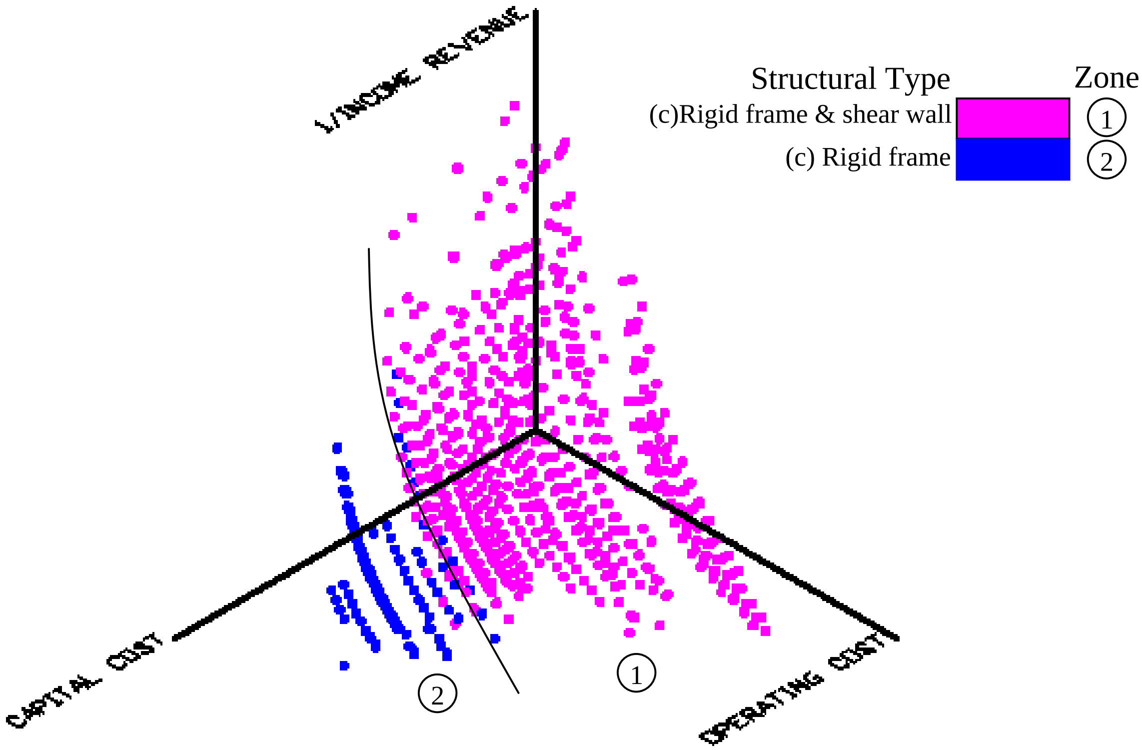

Figure 4.21: Example 3- Structural Type Pareto Zones

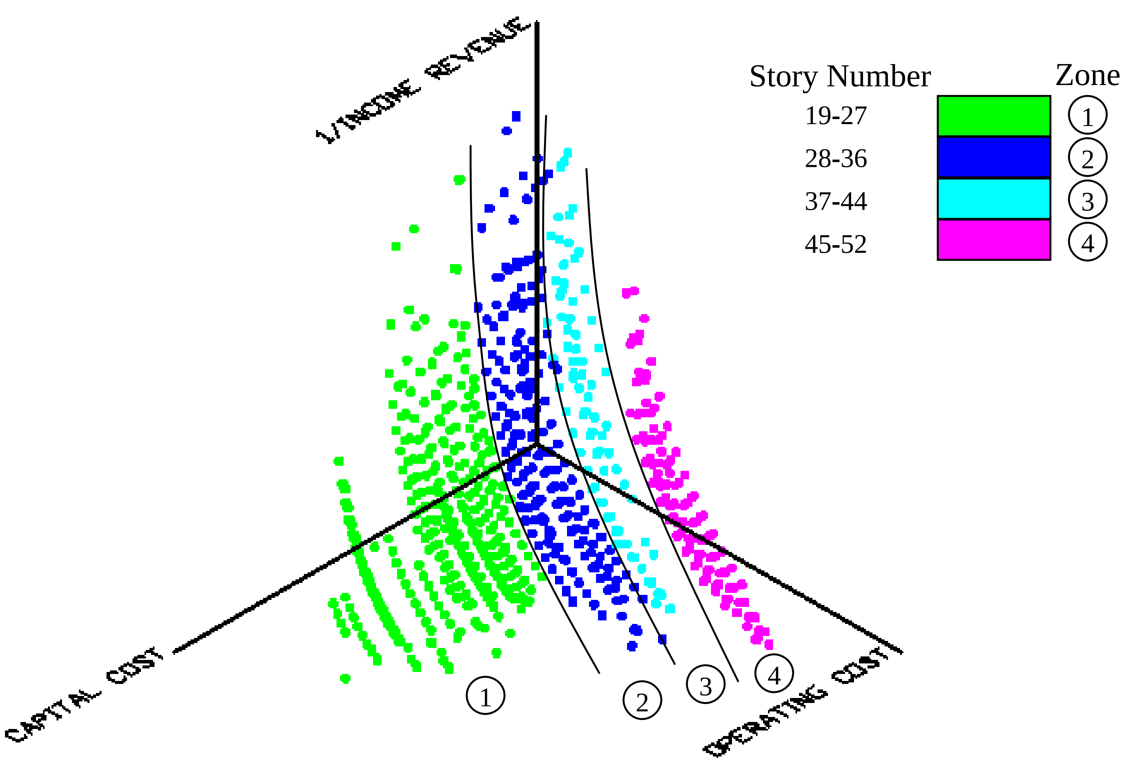

Figure 4.22: Example 3- Story Number Pareto Zones

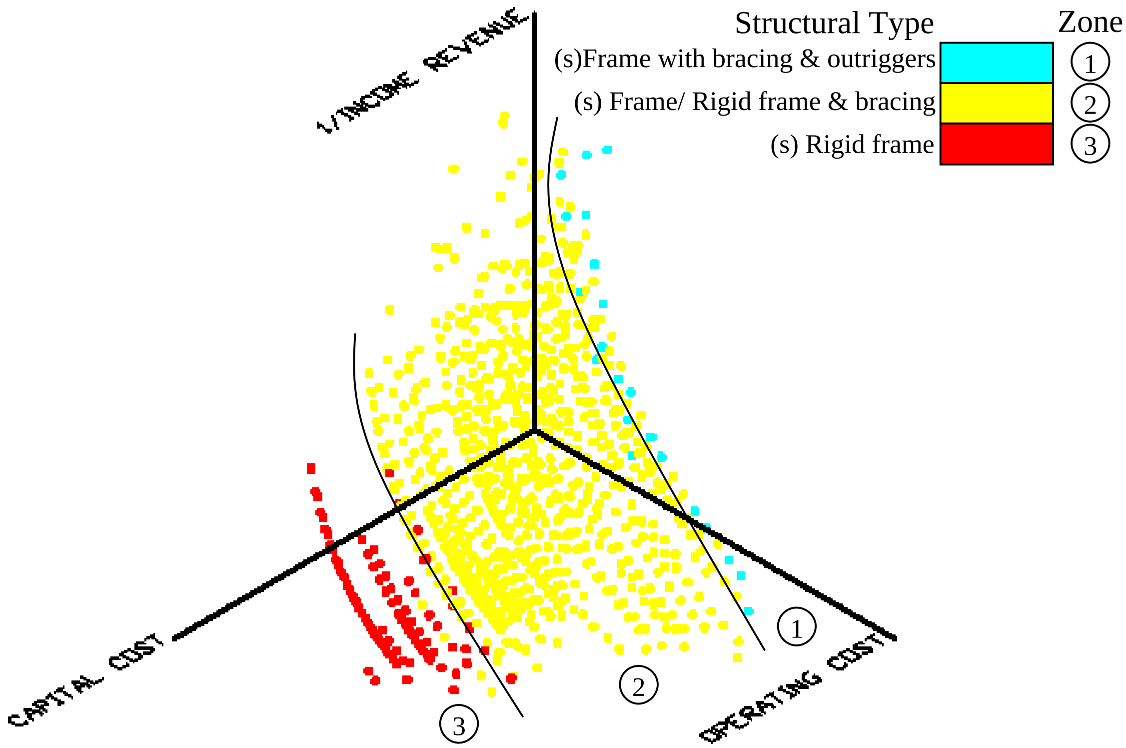

Figure 4.23: Example 4- Structural Type Pareto Zones

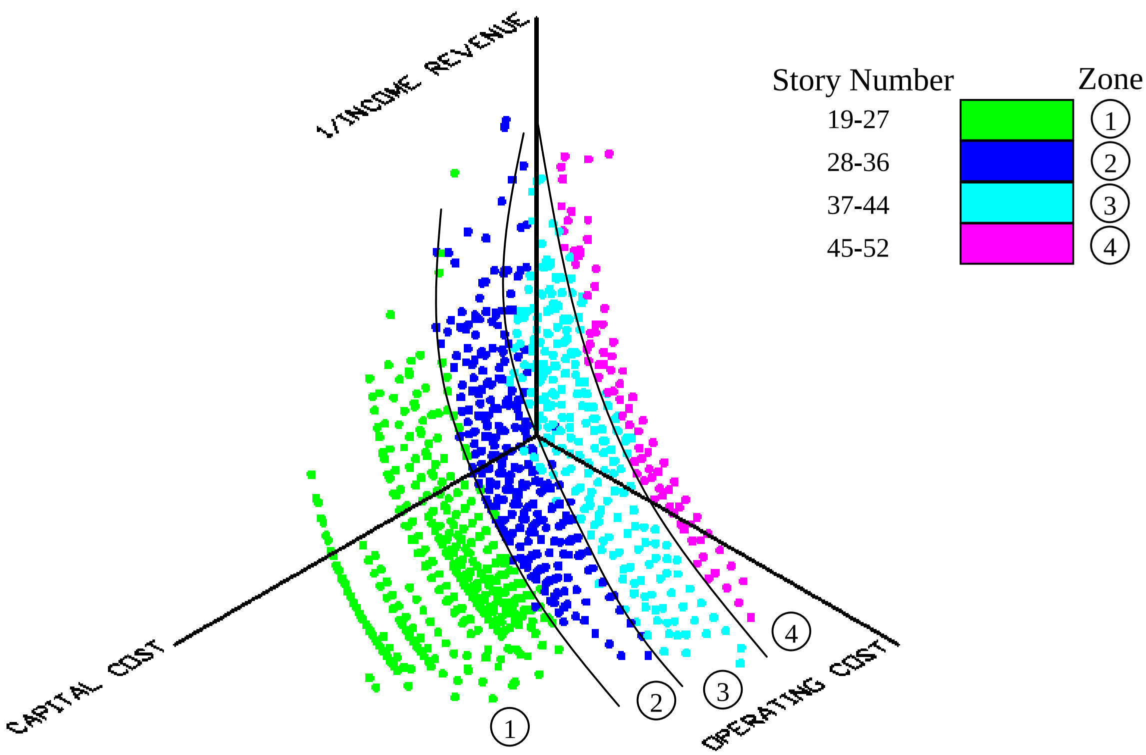

Figure 4.24: Example 4- Story Number Pareto Zones