Chapter 3:
Deductive Analysis

Conceptual Approach

The basic conceptual approach of our analysis has been used before (e.g. Martin and March, 1966; Keeble, 1969; Diamond, 1976). It is to combine a number of factors systematically in the development of a range of layouts, and analyze the effects of these factors on the resulting densities and urban patterns. Several factors may affect densities; these are incorporated into our analysis as the following independent variables.

Dwelling Form:
The most important factor is obviously the dwelling form. Consequently, the dwelling form is the first and main variable in our analysis. The range of possible dwelling forms we could have explored is quite large, from simple single family detached housing, through semi- detached and variations of duplex and quadruplex combinations, cluster housing, row housing, a wide range of low-rise multifamily housing types, to the many existing variations of high rise dwelling complexes. Within these types variations in floor plan characteristics and number of storeys could of course also have significant effects on densities and the resulting layout patterns.

Constraints of time and resources limited our ability to address the full range of possible dwelling forms. Therefore we selected for investigation four basic types which represent the polar and some intermediate points on this range: single family detached housing, single family row housing, low rise multi-family garden apartments, and high-rise multi-family apartments. Within each basic dwelling form, a few major variations in configuration were tested; these are the results of combining differences in form (e.g. indentations or projections) with other physical variables as shown in Figure 3-1.

Dwelling Size:
Within each dwelling form, variations in size are possible, which could have density effects (see, e.g. Windsor, 1979). Our analysis includes systematic variation in dwelling size, as a result of chan-

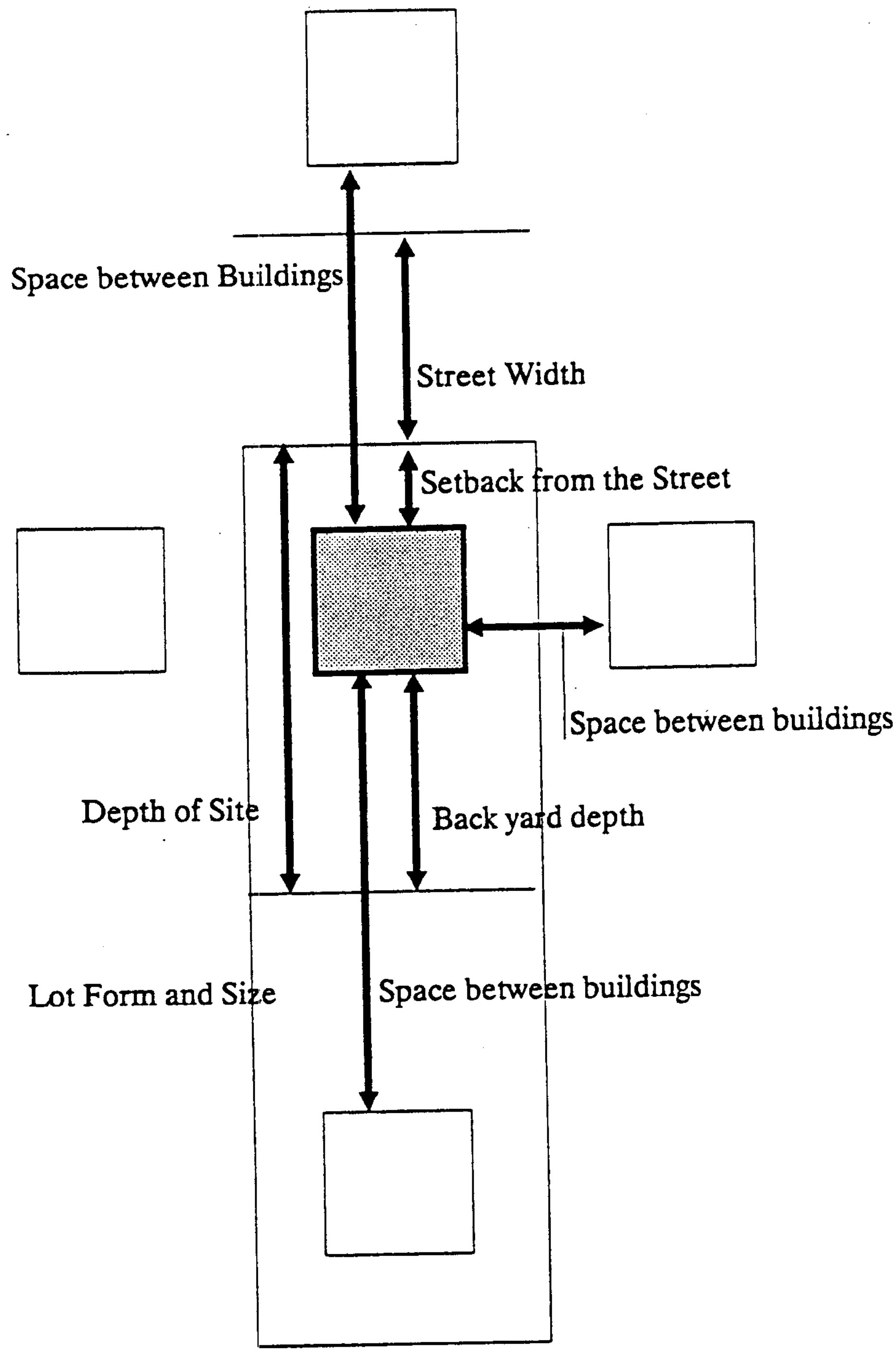


Figure 3-1: Physical Variables.

ges in floor plan area and in height. Thus single family detached dwellings are represented in 25'x40' and 30'x40' floor plans and in single storey and double storey versions. Row housing comes in 18'x22', 18'x30', floor plans, and in 2-floor and 3-floor heights. Garden apartments come in 3- and 4-floor variations, and range in area from 800 to 1650 square feet. High rise apartment complexes range from 8-12 floors (while this does not affect layouts necessarily, it interacts with density through the impact on parking requirements) and include apartments ranging from 500 to 1200 square feet.

The combinations of size, height and configuration were developed to be representative of a realistic range of residential dwelling arrangements, responding to market characteristics and the needs of a diverse population. Thus single family housing might be more compact for smaller families buying their "starter" home, while larger dwellings house larger and more mature households, and in multifamily complexes, small "studio" apartments appealing to the young single person or couple may be combined with larger apartments for older small families.

Lot Size:
Within each dwelling type, lot sizes vary too. For row housing this is the direct result of variation in dwelling plan; in other dwelling types, lot sizes were systematically varied in association with housing size and configuration to produce reasonable combinations. Thus, for single family housing, lots were changed in combinations of width and depth ranging from 36' to 133' width and 100' to 350' depth. Row house lot widths varied with the dwelling widths, from 12'to 35', and depths ranged from 60'to 125'.

Lots for multifamily housing are identical to their blocks; these were also systematically varied (see below). For multifamily dwelling forms another factor affecting what might be analogous to the single family dwelling's lot is the configuration of dwelling units on the building's floor plan. Possible configurations which were tested in apartment housing layouts are the "point" (a small number of units grouped around a common core), single and double loaded corridor plans, single and double loaded "core" plans (i.e where apartments are served by separate vertical circulation cores) and complex configurations involving combinations of the above. For low-rise apartment housing blocks were varied from 210' to 440' width and from 400' to 650' depth. High rise housing blocks ranged from 200' to 400' wide, and from 250' to 550' deep.

Block Configuration:
The block is the uninterrupted area of land bounded by streets. Block sizes and configurations can also affect GRD (cf. Flachsbart,

1979). There is obviously a close relationship between dwelling form and lot size, site layout, and block size and configuration. In terms of architectural design, block size and configuration are usually given. However, in development and site planning and urban design the block, as a result of the layout of streets and the disposition of buildings, is also a variable under the designer's control.

In this analysis, block sizes and configurations were systematically varied. Variations consisted of permutations of block sizes and three "block variables". The "block variable" represents the combination of the disposition of the surrounding streets and of the building masses in the block. In "parallel" blocks the block is a simple rectangle and the buildings are massed parallel to its long or short sides. In the "perimeter" block the building masses follow the perimeter of the rectangular block. The "penetrating" block diverges from the simple rectangles of the two former types, and includes "dead end" streets (often serving parking areas) penetrating the block.

Block sizes were the result of the interaction between the disposition of dwelling types and the "block variables". For single family detached dwellings block sizes ranged through a minimum of 360'x 250' to a maximum of 700'x 400'. Row housing occupied blocks ranging from 380'x 120' to 440'x 480'. Garden apartment blocks ranged from 210'x 400' to 440'x 800', while high rise apartment housing blocks ranged from 225'x 250' to 400'x 460'. Since the block area provides the denominator for the density measures, the variation in block sizes does not affect the analysis' results, and is simply included as a design factor.

Density Measures:
The dependent variables in this analysis are the density measures which we defined and reviewed above: NDD and GRD. Neighborhood Density and City Density are beyond the scope of this analysis, related as they are to the two former by another factor: the allocation of land for nonresidential neighborhood and citywide uses. In addition to NDD and GDD two other measures are computed for each of the schemes generated by the combinations of the variables described above. They are the Coverage and the Floor Area Ratio (FAR).

Method

Ninety nine schemes were developed combining the variables described above. Designs for the schemes reflect accepted or standard configurations and requirements of access, space between buildings, parking requirements etc. They are analytical "ideal types", so they do not aspire to architectural or design excellence, originality, diversity or stimulation. Obviously real-world designs will differ from these schematic layouts; the similarities and differences are explored later (see Chapter 4).

These schemes are shown in Appendix A. There are 24 variations of single family detached housing, 28 schemes of row housing, 37 garden apartment layouts, and 10 arrangements of high-rise multifamily housing. Table 3-1 presents a summary description of all these variations.

The information yielded by these schemes was the subject of two kinds of analysis. First, we are interested in the relation between dwelling forms and density measures. Since dwelling forms are nominal categories, this is not a relationship that is suited to statistical analysis. A simple array of the observed densities by dwelling form and subtype is sufficient to display whatever relationship may exist. This is shown in Figure 3-2.

Second, any relationships between any of the above variables, and the density measures related to the schemes resulting from their combination, would be of interest. Parametric statistical analysis

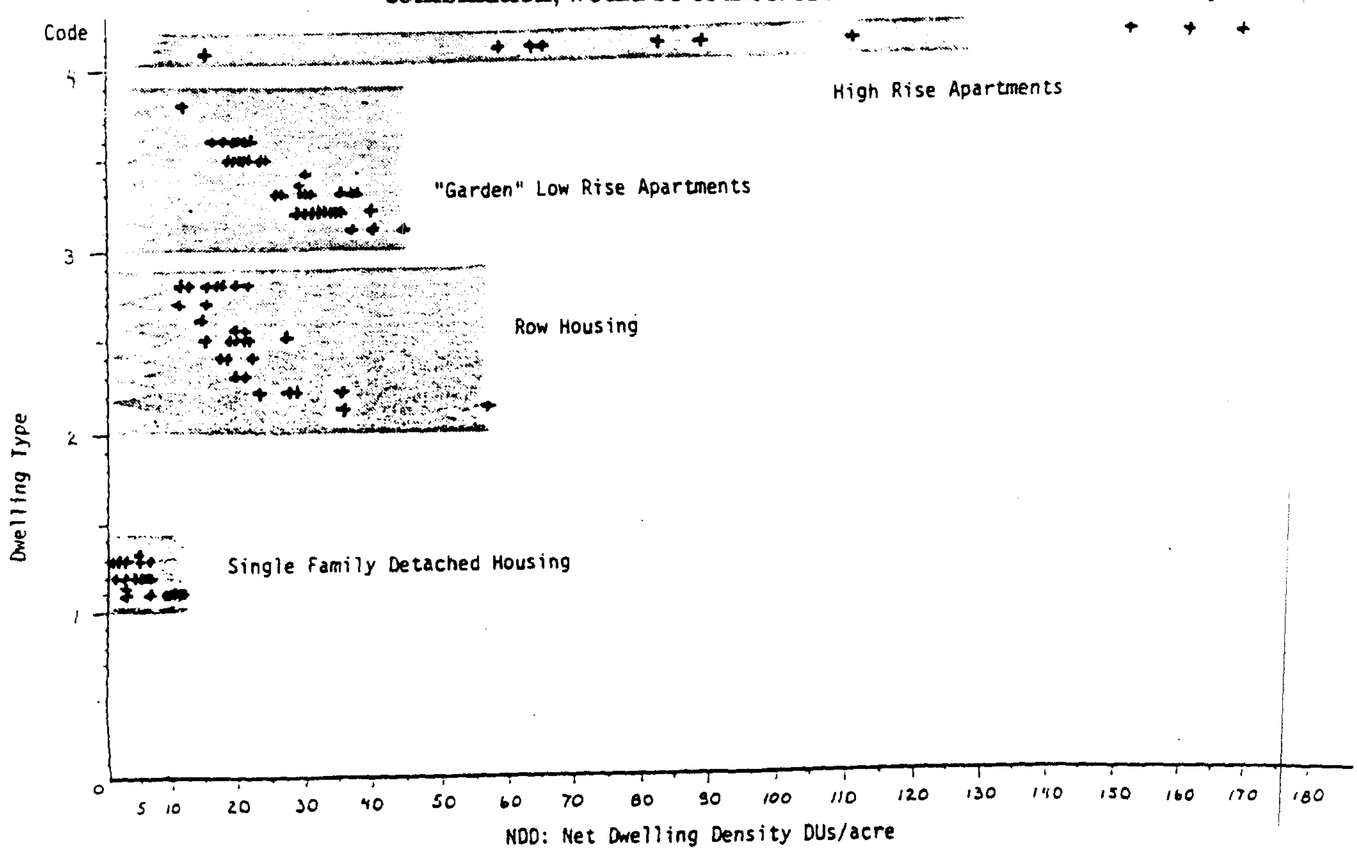


Figure 3-2: Distribution of NDD by Dwelling Types.

Code	Lot size 1	Lot size 2	Lot size 3	Block size	Block area	GRA acres	NDD	GRD	Cover (net)	FAR
1111	20 @ 36'x 125'			250' x 360'	2.10	2.70	9.700	7.400	0.27	0.27
1112	14 @ 50' x 100'	4 @ 62.5'x 100'		200' x 475'	2.20	2.80	8.300	6.300	0.23	0.23
1112	12 @ 66.7x 175'			350' x 400'	3.20	3.90	3.750	3.100	0.10	0.10
1121	4 @ 54' x 100'	8 @ 36' x 100'	8 @ 36' x 126'	252' x 364'	2.000	2.600	10.10	7.80	0.28	0.28
1122	10@ 70' x 150'	2 @ 100' x 175'		350' x 400'	3.200	3.900	3.750	3.100	0.100	0.100
1123	8 @ 50' x 100'	8 @ 50'x 137.5		200' x 475'	2.200	2.800	7.300	5.600	0.200	0.200
1131	40' x 90' (typ)			420' x 420'	3.600	4.400	10.60	8.700	0.300	0.300
1131	26 @ 50' x 90'			350' x 400'	2.850	3.900	9.100	6.600	0.250	0.250
1131/3	22 @ 40' x 100'	8 @ 53' x 100'	2 @ 40' x 87'	440' x 350'	3.500	4.300	9.000	7.400	0.250	0.250
1212/3	6 @ 133'x 175'			350' x 400'	3.200	3.900	1.900	1.500	0.060	0.080
1212/3	12 @ 60'x 125'			250' x 360'	2.100	2.700	5.800	4.400	0.180	0.180
1213	14 @ 70' x 100'			200' x 490'	2.250	2.900	6.200	4.800	0.190	0.280
1222	6 @ 83.3'x 95'	4 @ 80' x 125'		250' x 350'	2.000	2.600	5.000	3.850	0.150	0.250
1223	8 @ 70' x 100'	6 @ 66.7'x97.5		200' x 475'	2.200	2.800	6.400	4.900	0.200	0.290
1223	8 @ 87.5'x 150'	2 @100'x 175'		350' x 400'	3.200	3.900	3.125	2.500	0.090	0.140
1233	20 @ 70' x 115'(typ)			520' x 350'	3.800	4.800	5.200	4.200	0.170	0.300
1312/3	6 @ 130'x 350'			700' x 400'	6.400	0.000	1.000	1.000	0.020	0.040
1313	12 @ 55' x 125'			250' x 330'	1.900	2.500	6.400	4.900	0.150	0.300
1313	12 @ 79.2x 100'			200' x 475'	2.200	2.800	5.500	4.200	0.130	0.260
1321	8 @ 60' x 100'	6 @ 55' x 120'		240' x 365'	2.000	2.600	7.000	5.400	0.160	0.320
1321/3	6@ 75' x 100'	6@ 66.7'x 125'		200' x 475'	2.200	2.800	5.500	4.200	0.130	0.260
1323	6@ 116.7 x 150'	2@ 100' x 175'		350' x 400'	3.200	3.900	2.500	2.000	0.060	0.110
1331/3	6 @ 70' x 90'	22@ 45' x 90'(typ)		420' x 530'	4.700	6.000	6.400	5.000	0.150	0.300
1333	16@ 87.5'x 115'			520' x 350'	3.800	4.800	4.200	3.300	0.100	0.190
2112	56 @ 12' x 60'	4 @ 21' x 60'		120' x 380'	1.100	1.500	57.10	39.00	0.470	1.400
2123	66 @ 12' x 70'	4 @ 32' x 70'		220' x 380'	1.900	2.500	36.50	28.00	0.300	0.900
2212	34 @ 18' x 60'	4 @ 28' x 60'		120' x 380'	1.100	1.500	36.20	25.30	0.330	0.660
2222	46 @ 18' x 60'	4 @ 38' x 60'		256' x 354'	2.100	2.700	24.00	18.70	0.220	0.440
2232	76 @ 18' x 60'	4 @ 38' x 60'		300' x 400'	2.750	3.400	29.10	23.30	0.260	0.520
2233	86 @ 18' x 80'	6 @ 28' x 80'	2 @ 28' x 80'	380' x 470'	3.400	4.200	27.90	22.40	0.250	0.500
2313	46 @ 18' x 100'	4 @ 38' x 100'		200' x 490'	2.250	2.900	22.20	17.10	0.280	0.560
2322	46 @ 18' x 110'	4 @ 38' x 110'		220' x 490'	2.500	3.200	20.20	15.80	0.250	0.500
2412	40 @ 18' x 120'	4 @ 43' x 120'		240' x 446'	2.500	3.100	17.90	14.10	0.300	0.600
2423	48 @ 18' x 120'	4 @ 39' x 120'		240' x 510'	2.800	3.500	18.50	14.70	0.310	0.620
2432	88 @ 18' x 90'	10 @ 38' x 90'	2 @ 28' x 90'	455' x 490'	4.300	6.000	23.00	16.70	0.380	0.760
2512	36 @ 20' x 75'	4 @ 30' x 75'		150' x 420'	1.450	2.000	27.60	20.00	0.380	0.760
2512	42 @ 20' x 100'	4 @ 30' x 100'		200' x 480'	2.200	2.900	20.90	16.00	0.312	0.625
2522	38 @ 20' x 80'	4 @ 30' x 80'		240' x 360'	1.900	2.600	21.20	16.30	0.290	0.580
2522	42 @ 20' x 100'	4 @ 30' x 100'		200' x 480'	2.200	2.870	20.90	16.00	0.290	0.580
2522	48 @ 20' x 100'	4 @ 30' x 100'		360' x 400'	3.300	4.000	15.80	12.90	0.220	0.440
2532	38 @ 20' x 75'	4 @ 30' x 75'		250' x 340'	1.950	2.500	21.50	16.60	0.300	0.600
2532	60 @ 20' x 80'	8 @ 40' x 80'		380' x 400'	3.490	4.200	19.50	16.00	0.270	0.540
2532	78 @ 20' x 90'	10 @ 30' x 90'		440' x 480'	3.900	5.700	22.40	15.40	0.310	0.620
2612	30 @ 20' x 125'	4 @ 40' x 125'		250' x 380'	2.200	2.800	15.60	12.10	0.290	0.580
2723	38 @ 25' x 100'	4 @ 35' x 100'		370' x 395'	3.400	4.100	12.50	10.30	0.220	0.440
2732	22 @ 25' x 80'	10 @ 25' x 93'	4 @ 35' x 80'	285' x 345'	2.300	2.900	15.90	12.50	0.270	0.540
2812	24 @ 25' x 75'	4 @ 35' x 75'		150' x 360'	1.200	1.700	22.60	16.10	0.470	0.940
2812	24 @ 25' x 125'	4 @ 35' x 125'		250' x 370'	2.100	2.700	13.20	10.30	0.270	0.540
2813	32 @ 25' x 100'	4 @ 35' x 100'		200' x 460'	2.100	2.750	17.10	13.10	0.290	0.580
2822	34 @ 25' x 85"	4 @ 35' x 85'		170' x 485'	1.900	2.500	20.10	15.00	0.410	0.820
2823	24 @ 25' x 110'	4 @ 35' x 110'		220' x 350'	1.800	2.300	15.80	12.10	0.330	0.660
2833	64 @ 25' x 90'	8 @ 35' x 90'		450' x 470'	4.100	5.700	17.40	12.50	0.360	0.720

Table 3-1: Density Layout Schemes.

Code	Lot size 1	Lot size 2	Lot size 3	Block size	Block area	GRA acres	NDD	GRD	Cover (net)	FAR
3115				385' x 400'	3.500	4.300	40.70	33.60	0.250	0.750
3125				390' x 530'	4.750	5.600	45.50	38.40	0.280	0.840
3135				240' x 580'	3.200	4.000	37.50	30.10	0.210	0.620
3215				325' x 500'	3.400	4.200	35.00	28.60	0.340	1.020
3222				310' x 460'	3.300	4.020	33.00	26.90	0.320	0.950
3223				440' x 800'	5.250	6.200	32.00	27.20	0.450	1.350
3226				380' x 460'	4.000	4.800	35.90	29.90	0.340	1.030
3226				380' x 410'	3.600	4.300	40.20	33.20	0.350	1.040
3233				290' x 550'	3.700	4.500	29.50	24.20	0.280	0.840
3234				290' x 570'	3.800	4.600	34.80	28.60	0.330	1.000
3236				300' x 460'	3.200	3.900	30.30	24.60	0.300	0.890
3236				340' x 460'	3.600	4.400	33.40	27.50	0.290	0.870
3311				350' x 400'	3.200	3.900	30.00	28.00	0.320	0.960
3314				210' x 400'	1.930	2.500	37.30	28.50	0.310	0.940
3315				330" x 440'	3.300	4.100	36.00	29.40	0.300	0.900
3321				300' x 400'	2.750	3.400	26.20	21.00	0.240	0.720
3324				270' x 450'	2.800	3.500	30.10	24.10	0.250	0.760
3325				530' x 570'	4.300	5.200	38.90	32.40	0.330	0.990
3334				350' x 500'	4.000	4.800	26.90	22.50	0.230	0.680
3335				240' x 500'	2.750	3.500	30.50	24.20	0.280	0.840
3335				280' x 560'	3.600	4.400	30.00	24.50	0.250	0.750
3335				300' x 460'	3.200	3.900	30.30	24.60	0.300	0.890
3412				250' x 370'	2.100	2.700	31.10	24.20	0.360	1.100
3513				285' x 300'	1.900	2.500	24.50	18.90	0.360	1.100
3522				300' x 440'	3.100	3.750	23.80	19.20	0.320	0.950
3523				450' x 450'	4.700	5.500	20.70	17.50	0.310	0.930
3526				430' x 440'	4.300	5.200	22.10	18.50	0.300	0.910
3533				320' x 450'	3.300	4.100	21.80	17.80	0.250	0.750
3534				375' x 510'	4.400	5.200	20.50	17.20	0.270	0.820
3536				440' x 500'	5.100	5.950	19.00	16.10	0.270	0.810
3611				380' x 390'	3.400	4.200	21.00	17.35	0.280	0.840
3614				250' x 460'	2.600	3.300	22.70	18.00	0.350	1.040
3614				300' x 480'	3.300	4.100	21.75	17.70	0.275	0.825
3621				370' x 500'	4.250	5.100	16.90	14.20	0.230	0.680
3624				320' x 530'	3.900	4.700	21.60	17.80	0.270	0.810
3634				410' x 580'	5.500	6.400	19.80	16.88	0.250	0.750
3635				300' x 650'	4.500	5.400	18.75	15.60	0.250	0.750
4122				200' x 230'	1.600	1.500	113.0	80.00	0.210	2.470
4222				250' x 150'	0.860	1.130	58.00	44.00	0.200	2.080
4321				340' x 340'	2.700	3.300	59.30	48.50	0.120	1.250
4323				225' x 250'	1.290	1.760	163.0	119.0	0.420	2.990
4334				250' x 400'	2.300	2.900	83.50	66.20	0.250	1.430
4413				290' x 400'	2.700	3.300	154.0	126.0	0.120	3.230
4424				350' x 375'	3.010	3.700	65.80	53.50	0.250	1.310
4521				400' x 460'	4.200	5.100	171.0	141.0	0.120	3.640
4621				225' x 325'	0.510	1.670	90.00	36.00	0.300	4.600
4713				280' x 350'	2.250	2.900	64.00	49.70	0.150	1.760

Table 3-1: (continued)

was used to seek relationships between variables that could be expressed in quantitative data. On the assumption that the dwelling form as a nominal variable might introduce spurious relationships or confuse relationships that might exist, all the analyses were either done or repeated with observations (the 99 schemes) sorted by dwelling form.

Two kinds of analysis were done. A set of simple regressions analyzed the relationship of each variable with NDD and GRD as the dependent variables. Four sets of partial correlations (each set for a different dwelling form) analyzed the association between NDD and GRD and selected variables, controlling for several other factors at the same time. Table 3-2 describes all these analyses.

Findings

Density Measures and Dwelling Form:
Review of the array of densities produced by the 99 schemes which make up our "observations" offers a mixture of support for and contradiction of the proposition that densities are highly associated with dwelling forms or housing types. Figure 3-2 shows these observations, which are, of course, only intermediate points of the complete set of observations which we would see if all possible combinations of the variables had been explored.

The densities generated by the schemes developed here are highly suggestive at their upper limits. At their lower limits, of course, they simply represent a deliberate cutoff in terms of reasonable design configurations. However, other schemes could be developed that could produce densities arbitrarily as low as desired. Thus the range of densities for each dwelling form is intrinsically open-ended towards the low end of the scale, but is limited upwards by constraints involving the nature of the dwelling form and its possible configurations, design, access and space requirements, and parking needs. Development of the schemes used here has fulfilled its purpose in showing how these factors, when incorporated into realistic layout designs, affect residential densities and limit the densities at which development of various dwelling forms is possible.

Figure 3-2 offers some confirmation of popular wisdom, and some surprizes. Accepted stereotypes are supported by the finding that conventional single family detached housing is subject to a clear maximum density limit: this is around 12 units per acre (naturally, this can be exceeded by "unconventional" development such as "carpet" layouts with enclosed patios or "zero-lot-line" development).

Simple Regressions

Variables	Adj.r^2	Sign.F	B (slope)	B const. (Y inter.)	B 95% Conf. Interval
ALL SCHEMES:					
NDD-GRD	0.77	0.0000	1.17	3.88	1.04-1.30
NDD-LOTAREA	0.12*	0.0003	*see Figure 3-2A		
NDD-FAR	0.81	0.0000	45.28	-5.35	40.85-49.71
GRD-FAR	0.77	0.0000	33.19	-3.81	29.58-36.81
SINGLE FAMILY DETACHED HOUSING ONLY:					
NDD-GRD	0.99	0.0000	1.29	-0.06	1.24-1.35
NDD-LOTAREA	0.56*	0.0000	*see Figure 3-2B		
NDD-NCOVER	0.95	0.0000	34.00	0.43	30.69-37-37
NDD-FAR	0.54	0.0000	23.60	0.79	14.40-32.80
GRD-LOTAREA	0.53	0.0000	(like Figure 3-2B)		
GRD-GCOVER	0.94	0.0000	34.11	0.26	30.27-37.95
GRD-FAR	0.52	0.0000	17.84	0.75	30.27-37.95
ROW HOUSING ONLY:					
NDD-GRD	0.98	0.0000	1.47	-2.43	1.38-1.55
NDD-LOTAREA	0.65	0.0000	-0.13	46.00	-0.16-9.05
NDD-FAR	0.53	0.0000	33.82	0.82	21.33-46.30
GRD-LOTAREA	0.71	0.0000	-0.001	33.58	-0.011- -0.006
GRD-FAR	0.46	0.0001	20.86	4.50	11.61-30.09
GARDEN APARTMENTS ONLY:					
NDD-GRD	0.69	0.0000	1.11	8.90	0.87-1.30
NDD-FAR	0.75	0.0000	46.58	-6.73	38.61-54.55
NDD-PKRQD	0.29	0.0001	-0.00094	0.0021	-0.0014- -0.00051
NDD-UNITSIZE	0.32	0.0000	-0.06	122.50	-0.39-0.577
GRD-FAR	0.71	0.0000	34.70	-5.74	28.17-41.22
GRD-UNISIZE	0.19	0.0013	-0.04	79.74	-0.07- -0.45
HIGH-RISE APARTMENTS ONLY:					
NDD-GRD	0.51	0.0124	0.74	52.49	0.21-1.27
NDD-FAR	0.72	0.0011	35.14	34.41	18.82-51.45

Partial Correlations (by Dwelling Types) for the following variables:

NDD on NRASQFT/UNITSIZE	GRD on GRASQFT/UNITSIZE
NDD on LOTAREA/NRASQFT	GRD on LOTAREA/GRASQFT
NDD on LOTAREA/UNITSIZE	GRD on LOTAREA/UNITSIZE
NDD on LOTAREA/FAR	GRD on LOTAREA/FAR
NDD on UNITSIZE/NRASQFT	GRD on UNITSIZE/GRASQFT
NDD on UNITSIZE/NCOVER	GRD on UNITSIZE/GCOVER
NDD on UNITSIZE/FAR	GRD on UNITSIZE/FAR
NDD on NCOVER/LOTAREA	GRD on GCOVER/LOTAREA
NDD on NCOVER/FAR	GRD on GCOVER/FAR
NDD on FAR/LOTAREA	GRD on FAR/LOTAREA

Key:
NDD = Net Dwelling Density (DUs/Net Residential Area)
GRD = Gross Residential Density (DUs/Gross Residential Area)
NRASQFT = Net Residential Area in Sq. Feet
GRASQFT = Gross Residential Area in Sq. Feet
LOTAREA = Area of Lot in Sq. Feet
UNITSIZE = Total Floor Area of Dwelling Unit in Sq. Ft.
FAR = Floor Area Ratio (Tot. Built Floor Area/Net Res. Area)
NCOVER = Net Coverage (Ground Floor Area/Net Res. Area - %)

Table 3-2: Analysis of Density Related Variables.

Row housing offers a range of densities that may be surprizing: the upper limit is around 57 units per acre. This is higher than the limit we found for garden apartments. Contrary to prevailing images, perhaps, these two dwelling forms overlap over almost their entire range of densities: from about 13 units per acre at the low end to the 46 units per acre which is the upper limit for low rise multifamily housing.

The upper part of the range of residential densities, from 60 to 170 units per acre, is occupied exclusively by high rise multifamily housing. This finding again confirms the rules-of-thumb that prevail among architectural, urban design and planning practitioners. It supports the implication that for developments seeking average NDDs of 60 units per acre or higher, a mixture of housing types including a proportion of high-rise apartments will be required.

In summary, this analysis reveals a clear association of certain parts of the range of possible residential densities with specific dwelling forms. This association is not as exclusive, however, as often supposed. The bottom end of the range, up to 12 units per acre, is the domain of single family detached housing. The middle portion includes much higher NDDs than expected, and occupies the range from 13 to 59 units per acre. This area is associated with single family row housing and (up to 45 DUs per acre) low rise multifamily housing. High-rise multifamily housing monopolizes the upper part of the range, from 60 to 170 DUs per acre.

Relations Between Variables:
The variables included in this analysis are shown in Table 3-2 above. Several did not show any significant relationships. The ones of interest are the following (except where indicated, their significance always = 0.000).

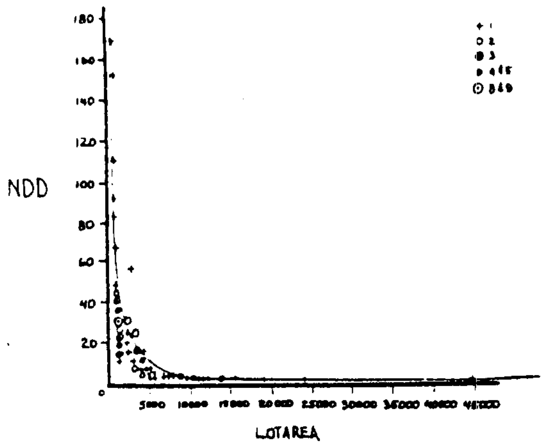
Net Dwelling Density (NDD) - Gross Residential Density (GRD). The relationship between NDD and GRD revealed by the analysis was expected. A strong association exists throughout the entire range of cases (the overall adjusted r^2 = 0.77); the slope of the function is just over one ($b = 1.17$). Sorted by dwelling types, this relationship varies somewhat: it is strongest for single family housing ($r^2 = 0.99$) and gradually weakens for multifamily housing; for the highrise apartments it is much weaker ($r^2 = 0.51$; sig.F = 0.12). This change is also predictable: as the size of developments increases, the gap between NDD and GRD will grow.

Floor Area Ratio (FAR). Overall, there is a significant association between density (NDD and GRD) and FAR (adj. $r^2 = 0.81$); this is also expected. The slope of the linear regression ($b = 45.28$) suggests that each increase of 100% in FAR would produce a 45 DU/acre rise in NDD. However, this finding is somewhat of an oversimplification, a statistical artefact resulting from the large number of cases. When sorted by dwelling type, the relationship between density and FAR is much less consistent. It is weak for single family housing (adj. $r^2 = 0.54$); this could also be expected, since here there is much less variance in number of storeys. The results for row housing are similar. But it is stronger for multi-family housing (e.g. for NDD adj.$r^2 = 0.72$).

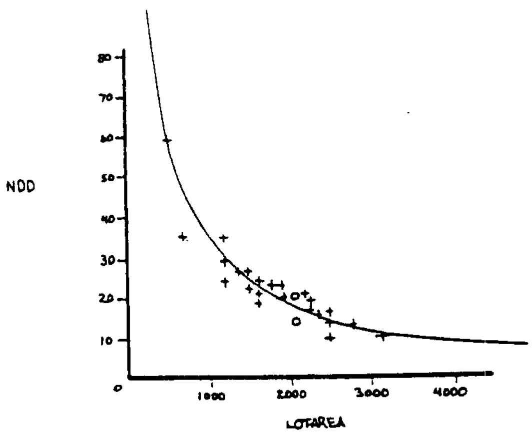
The partial correlation analysis confirms that FAR can be a significant factor, but with some qualifications. For single family detached housing, FAR is correlated with density (0.86) when controlling for unit size and for net or gross area of the block (0.73), but when controlled for coverage and lot area the association disappears. For row housing the relationship is strong, even when controlled for other variables (from 0.84 for FAR-GRD controlling for unit size, to 0.77 for FAR-NDD controlling for net coverage). For garden apartment housing, however, when controlled for other variables, the relationship between density and FAR disappears. It reappears strongly in high rise housing (this is not unexpected) where it is the only factor, indeed, to show any significant association with densities (with NDD: 0.91 controlling for block area, and 0.84 controlling for net coverage; with GRD: 0.81 controlling for gross residential land area, and 0.75 controlling for coverage).

We can conclude that there is an evident association between FAR and densities. Viewed in the aggregate, it could be expressed like our overall regression in a simple multiplier, confirming what is intuitively obvious: increases in FAR will produce higher densities. But in fact it is a more complex interaction which varies by dwelling type, and may be mediated by other factors.

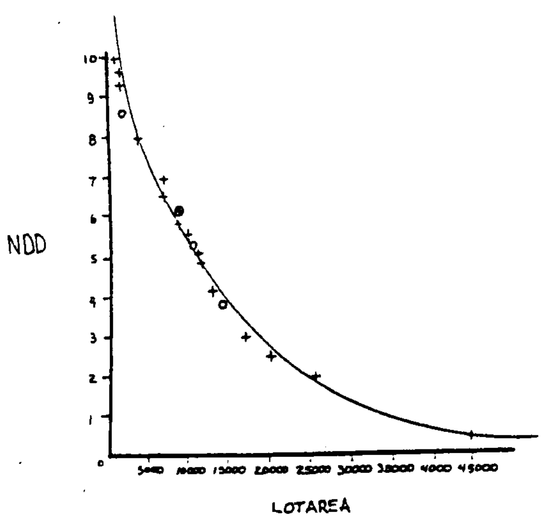
Coverage (net and gross). Regression analysis of all the cases shows no relationship between densities and coverage. This was a bit unexpected, but is explained when the cases are sorted by dwelling type. Single family detached housing does exhibit a strong relationship (adj. $r^2 = 0.95$); this is confirmed by the partial correlations, which are strong (0.94 to 0.97) even when controlled for other variables. For this type of housing the relationship between density and coverage can be expressed in a simple multiplyer: a 10% increase in coverage will add 3.4 DUs/acre to the NDD.



A: ALL DWELLING TYPES



B. SINGLE FAMILY DETACHED HOUSING



C. ROW HOUSING

Figure 3-3: Density-Lot Area Relationships.

This is clearly not a necessary arithmetical function. Rather, it seems to be the expression of a constant design relationship. This relationship is difficult to account for, since obvious possible connections to lot sizes or unit sizes are excluded by the results of the partial correlation analysis. In the other dwelling types multiple storeys reduce the effect of coverage on density to insignificance.

Lot Area. The relationship between densities and lot area is complex. The overall linear regression (for NDD: adj. $r^2=0.12$, sign.F=0.0003) fails to express the strong relationship (see Fig. 3-3.A) which, as the separate analyses show, is mediated by dwelling types. The first dwelling type, single family detached housing, exhibits an exponential function (Fig. 3-3.B) which, as expected, indicates an inverse relationship between lot size and density (i.e as lot area increases, densities fall). A similar, though flatter and more diffuse, relationship appears for row housing (Fig. 3-3.C). The partial correlations confirm the relationship between densities and lot area, though it is weaker (-0.67, -0.73) when controlled for unit size and block area. For the multifamily housing, lot area drops out as a relevant variable.

Dwelling Unit Size. Since the sizes of dwelling units in the designed cases do not vary continuously, linear regression analysis fails to reveal any association between them and densities (the results for lot areas are similar, for the same reason). The partial correlations show a weak negative association, however, for single family detached housing, which is much stronger (-0.85 to -0.90) for row and multifamily housing, even when controlled for other variables. This suggests that larger dwelling units are associated with lower densities, confirming what we have intuitively known all along. It is only surprising that the association is stronger for multifamily than for single family housing, since the reverse would be expected.

Conclusions

The following conclusions emerge from the findings of the deductive analysis:

* Dwelling form is almost as important in relation to density measures and their effects on urban form as has generally been supposed. All variables affecting residential densities are mediated by dwelling form, and some dwelling forms are closely associated with specific ranges of net dwelling densities and gross residential densities (see below).

* The relationship between dwelling form and density measures is not completely determinate, but some dwelling types are associated with particular parts of the entire range of residential densities. Among the dwelling types included in this study, the following rellationships appear:

  - single family detached housing occupies the NDD range from less than one to 12 DU/acre;

  - row housing and low-rise garden apartments share the middle densities in the range, with maximum NDD of 59 DU/acre and 46 DU/acre respectively;

  - high rise apartment housing claims the high end of the range, from 60- 170 DU/acre.

* Several variables are associated with density, but in complex relationships which are not simple mathematical functions. Usually these associations are the result of design considerations reflected in site development schemes, and a complex interaction of site and dwelling unit related variables. Variables which are associated with NDD and GRD are:

  - floor area ratio (FAR), for which overall regression analysis shows a multiplyer of 45 DU/acre for each 100% increase in FAR; however, this relationship is less consistent when disaggregated by dwelling form.

  - coverage is significantly related to NDD and GRD for single family detached housing only; here the multiplyer is a 3.4 DU/acre increase in NDD for every 10% rise in coverage.

  - dwelling unit size and lot area are sometimes related to NDD and GRD in a complex and variable fashion; these associations are too inconsistent to be of much significance for practical purposes.