DESIGNING CONSTRAINTS FOR CAPACITY ANALYSIS OF RESIDENTIAL FLOOR AREAS

A THESIS

SUBMITTED TO THE GRADUATE SCHOOL

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS

FOR THE DEGREE

MASTER OF ARCHITECTURE

BY

JING QIANG LI

ADVISER: DR. STEPHEN H. KENDALL

ACKNOWLEDGEMENTS:

I would like to express my sincere gratitude to my adviser, Professor Stephen H. Kendall for his enormous help and encouragement with my thesis and all of my studies in Ball State. I do appreciate that I worked as an assistantship with him during which learning has been the most stimulating and memorable experience under him.

I would like to express my special thanks to Professor Michele Chiuini, for his constructive suggestions on the main direction of my thesis. I would also like to express my special thanks to Timothy Gray for his valuable advice on the methodologies with regard to the condominium case study of this thesis.

I am very grateful to my parents, my sisters, brother in-law and my 3-year-old nephew for supporting me to come here and undertake this study. Only with their endless love, could I have studied at Ball State University and finish my study.

ARSTRACT

THESIS: Designing Constraints for Capacity Analysis of Residential Floor Areas

STUDENT: Jing Qiang Li

DEGREE: Master of Architecture

COLLEGE: College of Architecture and Planning

DATE: July 2004

PAGES: 146

This thesis focuses on the development of design constraints for use in analyzing the capacity of the residential units' floor areas in Open Building projects. Two cases are used to demonstrate the use of these constraints: a vacant office building (Kales Building) being converted to residential occupancy; a new multi-story building the lower floors of which are hotel rooms and the upper floors are residential condominium units.

The thesis suggests that these constraints and the capacity analysis of residential floor areas associated with them can assist design teams, at the beginning of similar projects; provide important "added value" to clients, and contribute to the long term "sustainability" or adaptability of buildings.

The first part of the thesis addresses the question of how to design a residential base building which can accommodate an optimal number and variety of fit-out unit layouts. The answer to the question links to the need for design constraints and points to their use in capacity analysis.

The second part of the thesis focuses on the deduction of "constraint-designing" for Open Building residential layout. Plumbing systems, which are one of the most significant barriers to the application of Open Building, are specifically and more deeply studied in this part. A series of constraints are developed, which can generally assist in designing and analyzing floor plate capacity. . It is akin to learning to know the rules before starting a game.

The third part of the thesis focuses on the demonstration of the uses of constraints in the design process of the conversion of an abandoned office building to residential uses.

The last part of the thesis demonstrates the use of constraints and capacity analysis in a new multi-story condo project.

In short, the paper is initially concerned with both the design concept and its application into detail levels in one of the many issues. It is a study of methods and technical rules of designing floor plan layouts when capacity analysis is the aim.

CONTENTS

Chapter I

Introduction

I-1 Introduction

The original motivation for this study comes from problems encountered in two academic design projects in which Open Building concepts were explored as possible solutions to serious problems. The first study was the conversion of a vacant office building to housing. The second was a study of a new multi-story building the lower floor of which are hotel rooms and the upper floors are residential condominium units. In the former exploration, the problem was to demonstrate how the process called “capacity analysis” could give added benefit to the developer, the architectural design team and future occupants. When given that task, I had only the most general idea of this process. After reading about the principles of open building and studying precedents, I began practicing the ‘operations’ of capacity analysis. It soon became apparent that these operations required careful development of design constraints. Once these design constraints were formulated, the capacity analysis work flowed much more quickly and easily. And soon I came to understand the operations involved in capacity analysis at a more intuitive level. In this study, I would like to formulate the design constraints that I have learned and demonstrate their use. These lessons may be of value to other design teams who may be interested in getting into this field.

The problem of the conflict between the simplified uniform habitations in high-rise buildings and demands from diverse and changing families is addressed in this study. The problem results from the conventional ways of designing and constructing such projects, processes that entangle decision-making as well as all the building components into one interdependent whole, leading to conflict, loss of quality, legal disputes, and difficulty in future adaptation.

However, the actual processes of conversion and new construction are dynamic. The market is also dynamic. Financing plans change, as does the regulatory environment. Further, there is good reason to think that individual needs should be accommodated (Habraken, 1999; Brand, 1994; Friedman, 2002; Kendall and Teicher, 2000). Moving into the "inflexible" dwelling units, occupants are bound to adjust themselves to layouts about which they have minimal to no control, and are inhibited from investing in improvements to them in any but superficial ways.

By making a distinction between a base building and a fit-out level, Open Building (O.B.) has the advantage of providing variations for individual dwelling units, variations which can be exploited by the developer in the case of rental units or by the individual buyers in the case of condominium units. In the adaptation case study mentioned above and which is detailed later in the thesis, the developer intends to "flip" the building from rental to condo within five years, so both conditions mentioned above apply.

Basic O.B. definitions are important for a reader of this thesis. The base building is the configuration of physical elements and spaces, which represents the more stable, longer lasting (as well as common) interests. The fit-out is the configuration of physical elements and spaces that represents of the individual occupant or tenant, and is therefore of a shorter life in general, from the standpoint of sustainable development and life-cycle analysis. In principle, the fit-out can be determined or changed without forcing changes to the base building, but the opposite is not true: a change of base building forces the fit-out to change. The relationship is, therefore, asymmetrical.

This thesis tries to show that applying O.B. concepts to residential building can offer significant contributions to the problems addressed above, as I hope the case studies in chapter two demonstrate. Evidence of the merits of OB is increasing internationally. (Kendall, 1999; Tiuri, 2001) But in all cases, given O.B.'s two-level organization (base building and fit-out), the question "what is the best design for the base building, such that it can provide optimum capacity for variable fit-out initially and over time?" must be answered. This is what the design process called "capacity analysis" seeks to solve. However, capacity analysis itself is based on certain assumptions, conventions and rules or constraints. Defining and "designing" these constraints is therefore an important element of capacity analysis.

In short, the thesis aims to demonstrate that applying O.B. concepts in high-rise residential building can help to solve the problems addressed above. Designing constraints and using them in capacity analysis can connect the theory to reality. Therefore, the study focuses on a clear formulation of design constraints needed for capacity analysis, with a special emphasis on drainage piping, one of the most problematic issues in high-rise residential buildings.

I-2 Problems in conventional design process and construction

The conventional design process that architects usually follow in practice is based on their life experiences and professional training in schools. Other forces directing architects' work are the conventions familiar to developers, banks, regulatory bodies, and construction organizations. To most people and even architects, it is "reasonable" to have a few typical layout plans that are deployed uniformly in the entire tower building. Few people will see it as a problem because the paradigm driving the design of high rise residential buildings has not changed since they were invented in the late 19^{th} and early 20^{th} centuries.

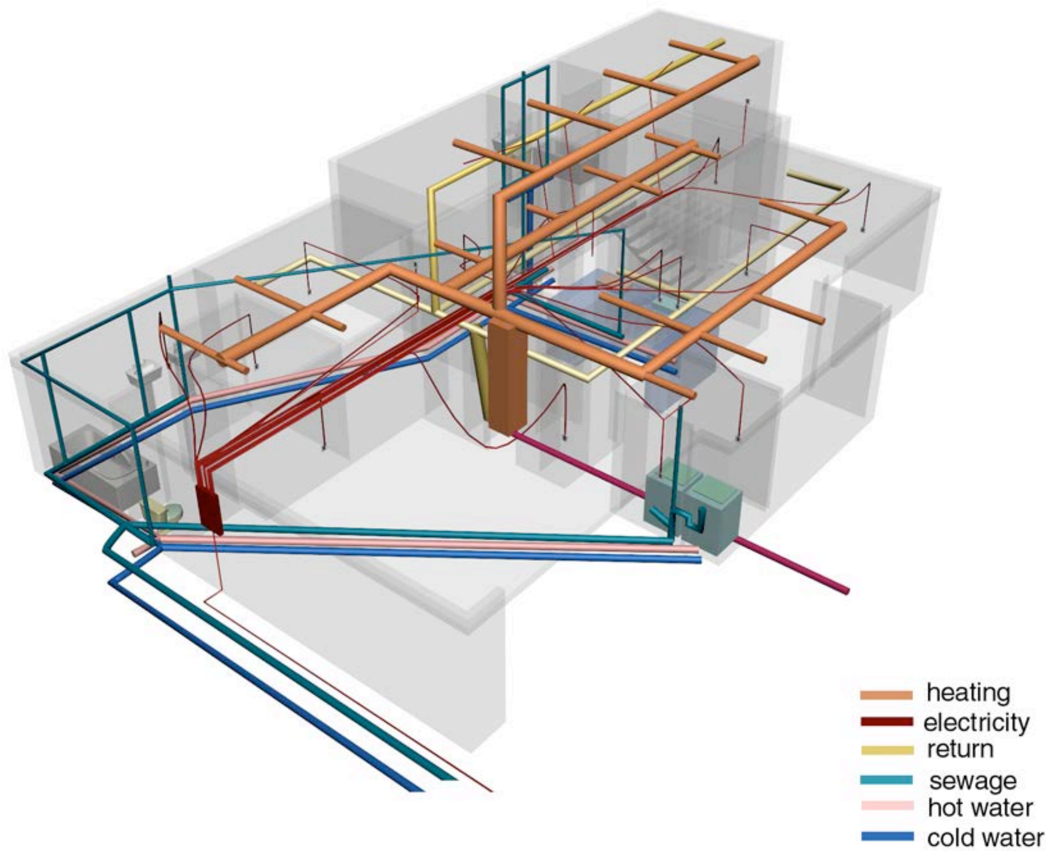


Figure I- 1 A typical detached house piping and wring diagram shows the disorganized "integration" of all parts, which causes difficulties for future adaptations. This is similar to a high rise dwelling, but in this case only shows one dwelling unit's entanglement whereas in high rise buildings there is another level of entanglement between individual units, which this thesis seeks to avoid.

In a conventional design process, the building is normally conceived as a unified "whole", made of a large list of technical parts or systems (see Figure I-1). There is no hierarchy of "levels" to guide deployment of building components. In high-rise buildings, architects design a set of residential unit layout plans, stack them, and weave all the building components from one unit to the other to make one building comprising one integrated system. For example, when a bathroom is located, the drainage pipes of its sanitary fixtures will be permanently buried into the concrete floor and positioned vertically into the same spot of each floor. Therefore, the location of the bathroom of one dwelling unit cannot be moved without implicating the dwelling unit layouts above and below. Because bathrooms play an important role in residential layout designing, when they are limited in only one location, the unit layout is basically defined, and therefore, no more layout variations can be developed. As a result, in high rise residential apartment building projects, conventional design methods can only offer "stacks" of simplified uniform layout plan. In addition, the conventional design methods also result in an overly rigid design process which increases unpredictable design loads for architects. When clients change their investment plans, for instance, they want to reduce or add some apartment units on certain floors – that is, to change the unit mix for marketing purposes as they see them at the present. This change causes the architect to start over the design process, because a change on one floor necessitates changes on other floors because of the closely interdependent MEP (mechanical, electrical, plumbing).

Despite the simplified uniform layouts, the conventional process brings possible risks to the developer in the dynamic market. The real estates market is a serious business that involves large financial investments and risks. A large number of market surveys are carried out before and even during the investment process in order to balance market demands and supply. For developers, the more "decision flexibility" they have, the less risk they face. But the present process does not provide adequate decision flexibility, thus making residential high rise development and conversion one of the most risky real estate investments.

In all, conventional design and construction processes result in simplified uniform units and rigid buildings. It causes unpredictable and uncontrollable conflicts and problems in both design management for the architects and market stratagem for the clients.

I-3 Life style focus

Nowadays, people pay more attention to their life styles than they did decades ago. They will renovate and decorate their dwellings to suit their life styles, such as re-paint a room, change tiles of the kitchen and bathrooms, change the ceiling shape, or split one room into two, etc.

However, all of these renovations are just slightly different; they do not change the original layout pattern because there are so many restrictions from the entangled conventional construction. Therefore, strict limitations face occupants in changing their units to meet their unique life patterns and changing household circumstances and budgets. These same limitations restrict a building owner from adapting the building's unit mix and layouts when the overall market changes.

But when we look at other product industries, many new products are designed to fit diverse lifestyles in order to be more competitive in the dynamic market. For instance, in the automobile industry, increasing numbers of customizing options are offered. In a given model, the inside mechanical setups such as engines, oil tank volume, etc are variables. Many appearance and interior options can be offered in term of colors, leathers or fabric seats, automatic or manual, convertible, sunroof or conventional roof, power window or manual, audio system and so on. With these customizing options, various combinations can be provided to the dynamic market. Similarly, this idea can also apply in the housing industry, by using contemporary techniques and methods to offer more unit variations for the market.

I-4 The conventional design process in building conversion

As a means of describing conventional practice in high-rise residential design and construction, two cases are used. The first is a conversion of an obsolete office building (the Kales building) to housing. The second is a new project now under construction - a multi-story building with several floors of luxury condominium units on top of a hotel base.

The following is a brief background on the Kales project.

The Kales building is an 18-story historic office building and was constructed in 1925 as the headquarters of the Kresge Company in downtown Detroit, and was designed by the architect Albert Kahn. It has been vacant since 1985. In 2001, the Mansur Real Estate Services Company, based in Indianapolis, began the process of purchasing the property and obtained the approvals and financing to proceed with its conversion to 80 apartment units. It is now nearly completed, but the story of its process is worth telling

Four years ago, the development company began organizing the financing-a mix of state and national historic tax credits and bank loans. In the beginning of the project, it conducted a market analysis to make a unit count decision, mix and layouts, as well as the rents. The first conversion design was based on those projections. Cost estimates were determined based on the architectural scheme and engineering designs. (Figure I-3)

However, the financing scheme had some difficulties, and other conditions in the market changed in term of interest rates and competition in the local market. These uncontrollable changes caused the marketing plan for the building to change. The architect completely revised the unit mix and floor plans (Figure I-4), with the same effect to the mechanical, electrical and plumbing designs and cost estimates. This happened three times (Figure I-5) for no additional design fees. At a certain point, a decision was made to “freeze” the design, to enable construction bids to be obtained and construction undertaken. Construction is expected to take one year.

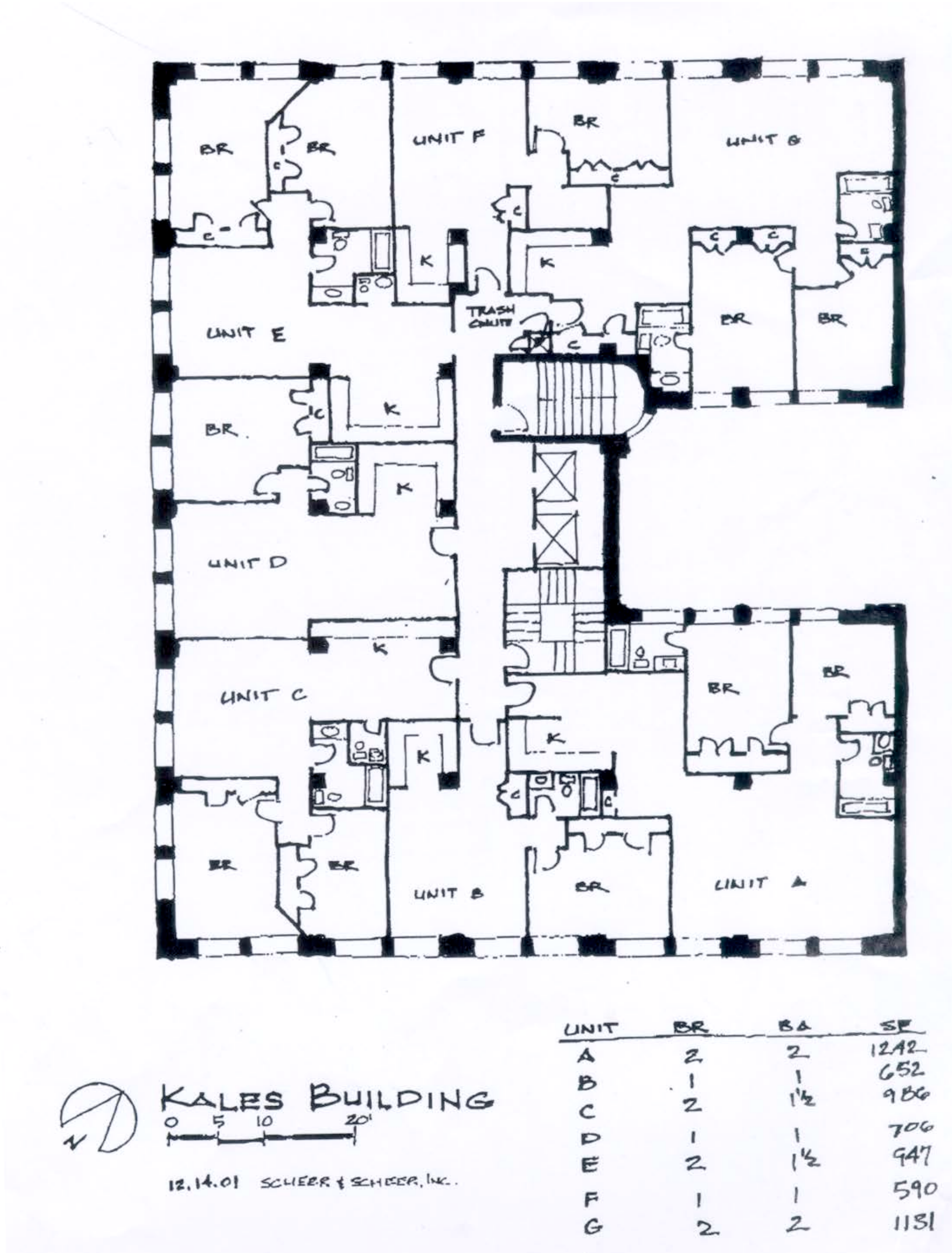
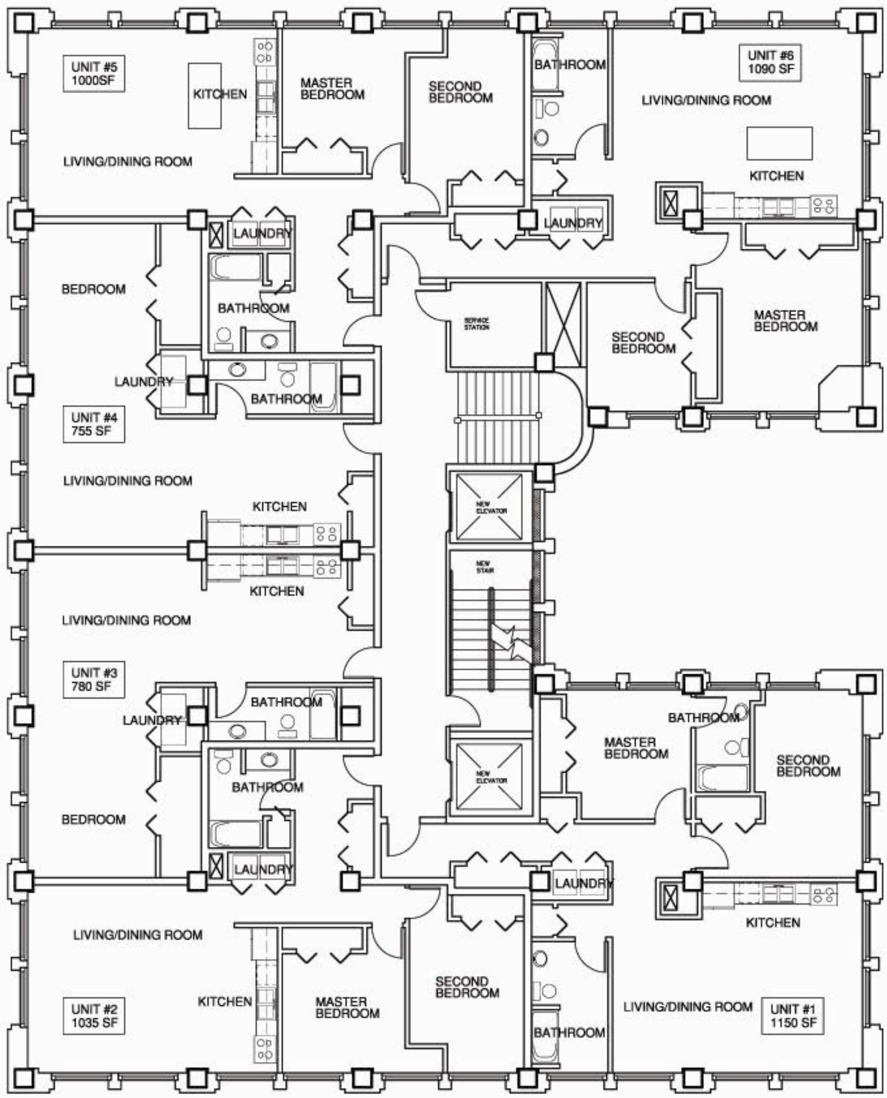


Figure I- 3 shows the first schematic design of one typical lower floor, drawn in December 2001. (SOURCE: BVH Architecture, INC. Detroit. Michigan)

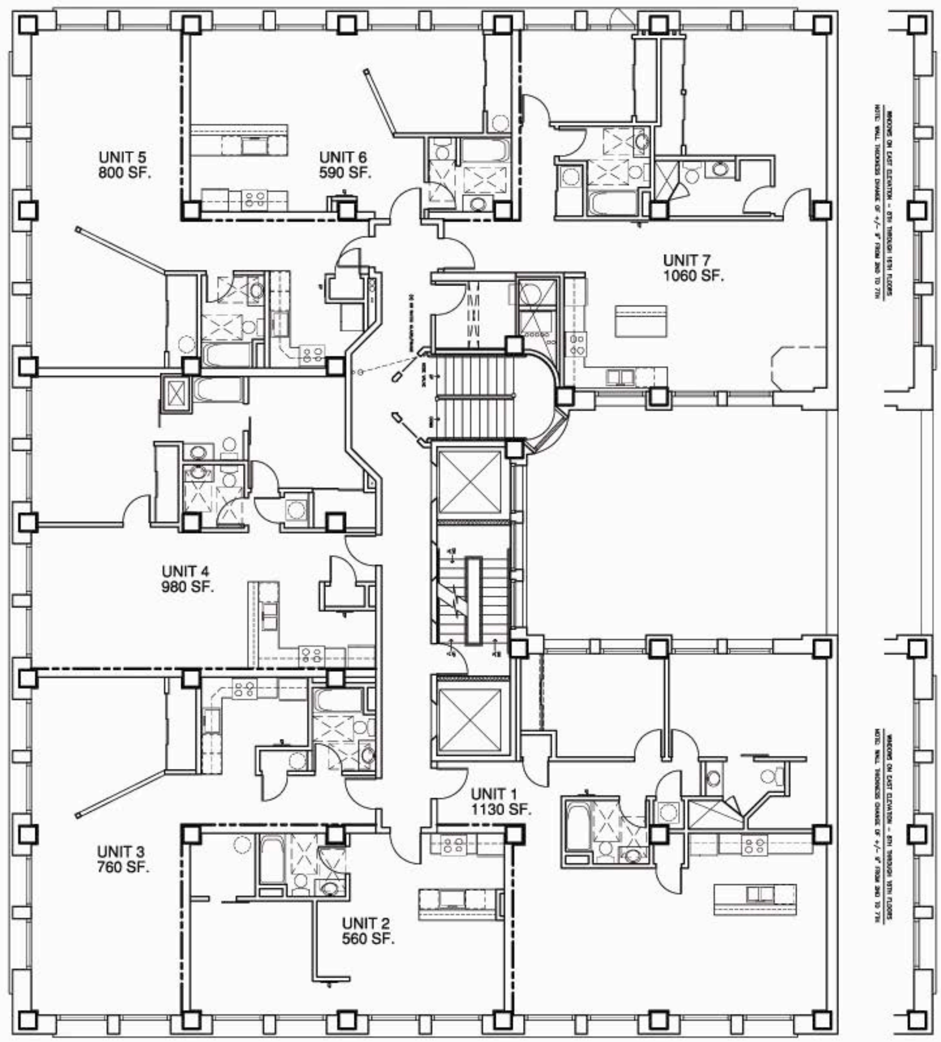


KALES- SIX UNIT FLOOR PLAN

UNIT	BR	BA	SF.
UNIT #1	2	2	1150
UNIT #2	2	2	1035
UNIT #3	1	1	780
UNIT #4	1	1	755
UNIT #5	2	1	1000
UNIT #6	2	1	1090

Figure I- 4 shows the floor plan layout drawing of the second design round in February 2002. There are 6 units in a typical floor from the 3rd floor to the 15th floor.

(SOURCE: BVH Architecture, INC. Detroit. Michigan)



KALES - TYPICAL FLOOR PLAN (3-18)

UNIT	BR	BA	SF.
UNIT #1	2	2	1130
UNIT #2	1	1	560
UNIT #3	1	1	760
UNIT #4	2	2	980
UNIT #5	1	1	800
UNIT #6	1	1	590
UNIT #7	2	2	1060

Figure I- 5 shows the third redo of the design due to the developer's new market analysis, in June 2002. Now there are seven units in a typical floor from the 3rd to the 15th floor.

(SOURCE: BVH Architecture, INC. Detroit. Michigan)

I-5 Observations from the Kales conventional conversion design process

Four problems emerged from studying the problems encountered in the back and forth design process in the Kales building conversion described briefly above.

1. *The problem of unnecessary and uncompensated work for architects and engineers when the developer's requirements are uncertain.*
2. *The problem of the insufficient decision flexibility for the developer.*
3. *The problem of the severe limitation of dwelling unit variations to offer to a shifting market, and*
4. *The problem of lack of provision for long-term adaptability.*

To approach these problems, new design methods are required, among other things. Open Building methods are explored in the study that follows as one part of a more comprehensive solution.

I-6 O. B. process as an alternative

The main concept of Open Building (O.B.) which is different from conventional building concept is to distinguish two decision making levels corresponding to two environmental levels and two markets with different incentives and dynamics:

Base Building – the more permanent part of the whole building, tied to the political, geotechnical, climatic and regulatory environment (structure, skin, public circulation, and main MEP systems). Base building is also sometimes called a "support", or "skeleton".

Fit-Out – the more changeable part of the whole, determined for each occupant space, with its own MEP systems, partitions, equipment, and fixtures. Fit-out is also sometimes called "infill" or "tenant work".

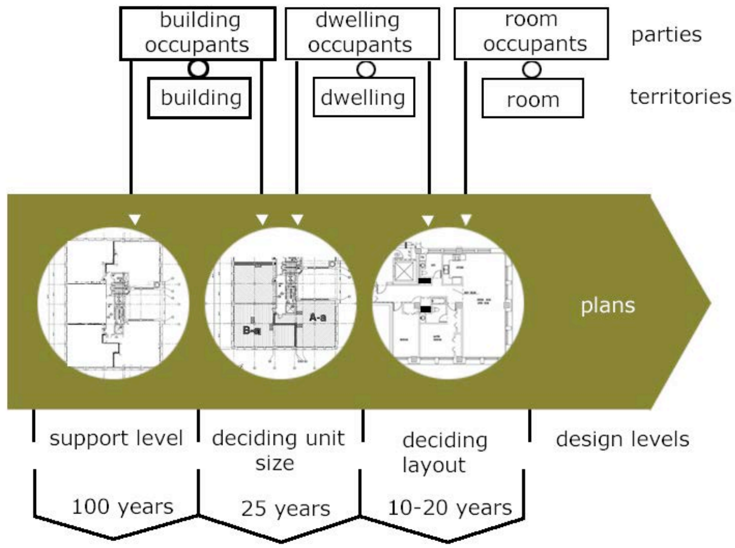


Figure I- 6 Describes how "levels" are related to a certain physical environment under the control of a party – e.g. a community group, a development company or a household or occupant. The idea is that decisions concerning a "lower level" (e.g. unit sizes) can be made within the constraints given by the higher level (derived from OBOM, TuDelft, 1990)

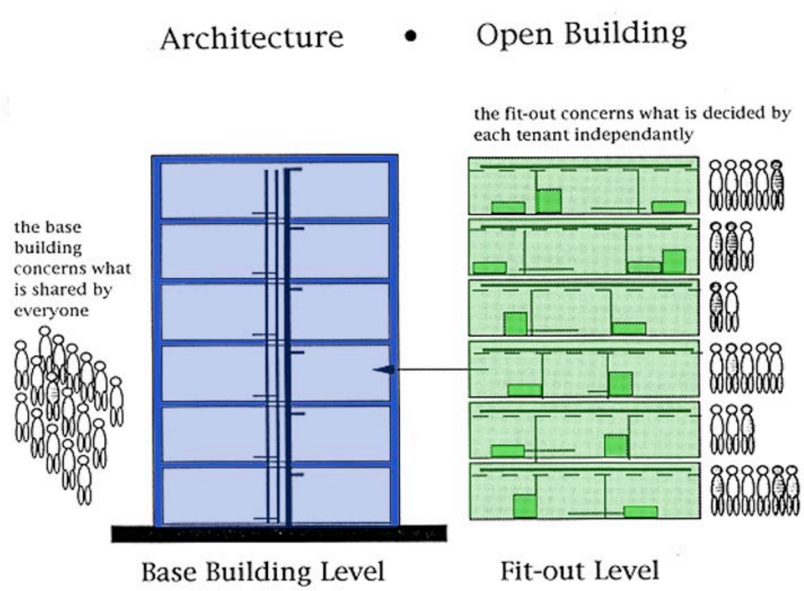


Figure I- 7 Open building offers methods and tools in managing the design and construction of buildings in respect to this distinction. (Kendall, 2003)

The process we are studying in this thesis is radically different from the conventional process. It has five objectives:

1. *Offer the developer decision flexibility in meeting current and future markets.*
2. *Enable the developer to defer decisions about unit mix and layouts without risk, by making each dwelling unit as autonomous as possible.*
3. *Address the extremely limited space on the site for logistics of construction.*
4. *Develop a process that enable maximum use of off-site "controlled environment" facilities to prepare ready-to-install "integrated fit-out kits".*
5. *Enable subsequent adjustment to the building to be done on a one-unit-at-time basis, including conversion to condominium units for sale, while assuring that improvements to the base building will minimally affect individual units.*

This thesis addresses objectives 1, 2 and 5.

The first step in an OB project involves a methodical design process in which a typical floor plate (proposed in a new building or "as-is" in a conversion) is analyzed to determine an optimum variety of unit sizes, given a "reasonable" target suited to the market. This involves a series of design studies in which two things are assessed. First, alternative placements of "demising" walls separating units are studied. Second, vertical MEP "stacks" are positioned. Given an initial or "trial" layout of demising walls and stacks, the capacity of the floor plate to accommodate a range of unit sizes and each "demised" space to accommodate a range of layouts is evaluated.

Then MEP stacks are re-positioned, and the same capacity analysis is repeated. These studies are done using a "test fit" process, in which accommodation capacity is evaluated given certain clearly defined constraints.

Before and during the "test fit" process, some technical constraints need to be set up as criteria that can be used in evaluating the "test fit" process. In this study, the focus is on the development of design constraints in the plumbing system, and more specifically in the DWV (drain, waste and vent) elements, with specific reference to the vertical MEP stacks and the "traffic management" of DWV lines within individual units.

In the "test fit" process, many layouts are developed, using constraints derived from conventions in the industry and from a variety of technical studies based on OB principles. In this "test-fit" process, some layouts were found to be unacceptable (comparing them to conventional layouts and the layouts proposed by the project architect) while some others are satisfactory. Then, based on lessons learned, the MEP stacks are re-positioned, and the "test-fit" process is repeated. This design process continues until an agreement is reached about optimum unit mix layout variety (Kendall, 2003). This design process is a "trial and error" process that eventually can become intuitive and may, in time, be supported by advanced computer aided design once the problems are clearly formulated.

Among all technical studies, plumbing is one of the biggest obstacles for O.B. implementations. Therefore, the technical studies in this thesis have focused on plumbing and other building components such as partition walls carrying the plumbing lines. Chapter II goes into detail on these technical issues and focuses on the development of a set of design constraints to help manage their complexity.

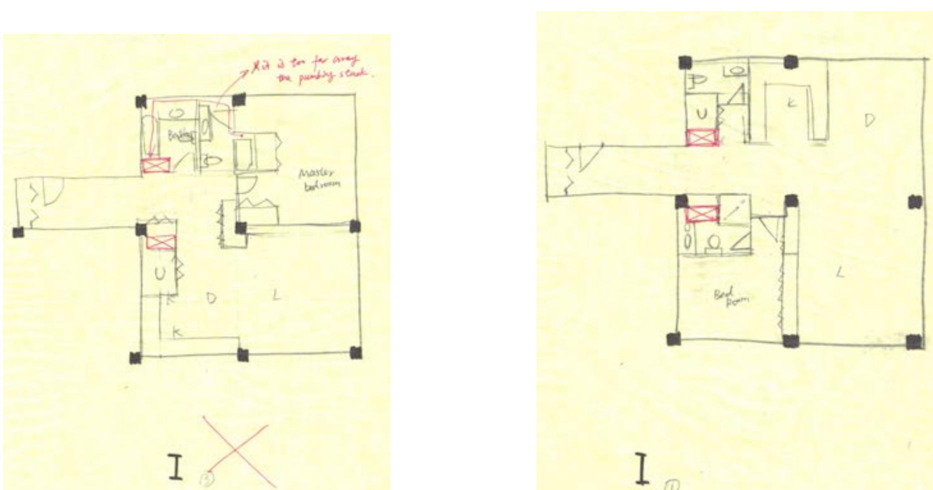


Figure I- 8 These are two images scanned from many sketches during the "trial and error" process. The left one was determined as a failure because the distance from the bathtub to the MEP stack is too long. The right image is one of the acceptable layout plans that were developed further.

CHAPTER II

Designing Constraints for Capacity Analysis of Residential Floor Areas

CHAPTER SUMMARY

This chapter is the main part of the thesis.

Capacity analysis and design constraints are described more fully, and their relationship defined. Many kinds of design constraints are needed for a full capacity analysis, some of which must be made explicit while many more are simply conventions and do not need to be explained in detail.

In doing O.B. capacity analysis, plumbing issues are one of the most difficult obstacles. Therefore this study focuses primarily on these issues and more specifically on the DWV (drain/waste/vent) subsystem. A set of plumbing-related constraints which can contribute to O.B. capacity analysis are proposed and their use demonstrated in two case studies presented in Chapter Three.

II-1 . Capacity analysis explained in more detail

Residential floor area capacity analysis is defined as a method to evaluate and determine how many reasonable layout variations a given space can accommodate. It is an examination between two levels of configurations. In the case of this thesis, the two configurations are the Base Building and the Fit-Out, defined in Chapter 1. The higher level - the Base Building - determinates the range of distributions of the lower level-Fit-Out. A well designed Base Building can accommodate – has capacity for - many Fit-out variations. Having such choices allows evaluation based on values important to the stakeholders involved. Therefore, capacity analysis is the study of the relation between the Base Building and the Fit-out. This thesis focuses on the methods needed to conduct capacity analysis and not on the specific values that specific stakeholders might bring to a decision process.

To determine a good Base Building, constraints such as construction methods and technical rules of the interface between the lower level and the higher level must be studied and clearly documented. Different spaces have different capacities. The physical factors affecting the capacity of a space are its shape, width, length, exterior walls and their openings, MEP interfaces, column arrangement, the ceiling high, structural system and so on.

The following diagrams – from a report on a pioneering project in the Netherlands - indicate basic principles in capacity analysis in terms of furniture groupings and their functional layouts. In Figure II-1, the left drawing describes the furniture layout in various arrangements for different kind of purposes, such as a dining room: a long dining table with four chairs in three sides of the long table or a wide table with two chairs in both longer sides. The former arrangement is 3-meter long and 1.2-meter wide; the later 1.8-meter long and 1.5-meter wide. The right side of the diagram describes how to place such configurations - shown to the left - in a given space module (shown by the hypothetical concrete walls shown in black). By placing the furniture layouts into this "trial" "fixed" base building space, it is possible to assess the accommodation capacity of one spatial unit. It is important to note that the criteria for measuring "optimum" or "reasonable" base building quality and fit-out variety are, in practice, agreements among the stakeholders and may vary from one project to another.

Capacity analysis, in this example, is thus a step by step analysis of spatial quality, by which a most effective spatial unit that can support the maximum variations is defined. Figure II-2 shows the next step – the application of the preferred space module to a whole building that can accommodate a suitable range of lower level variants. Therefore, it goes to another "higher" lever of capacity analysis.

This example mainly focuses the spatial capacity analysis on the relation between furniture arrangement and certain spaces. This simple demonstration is given in order to indicate that to do capacity analysis, some rules or constraints are required, otherwise, variations and their value cannot be determined nor their feasibility assessed, nor choices made.

Studying and developing design constraints and rules before undertaking a specific design is akin to making and learning rules before playing a game or sport. For instance, in playing tennis, rules must be known such as serving rules, scoring rules, what is off-side or a violation, etc. After knowing all the rules, players can develop “plays” and many strategies without violating the rules. Similarly, studying and making design constrains equals making and learning rules in tennis; and capacity analysis equals strategy analysis.

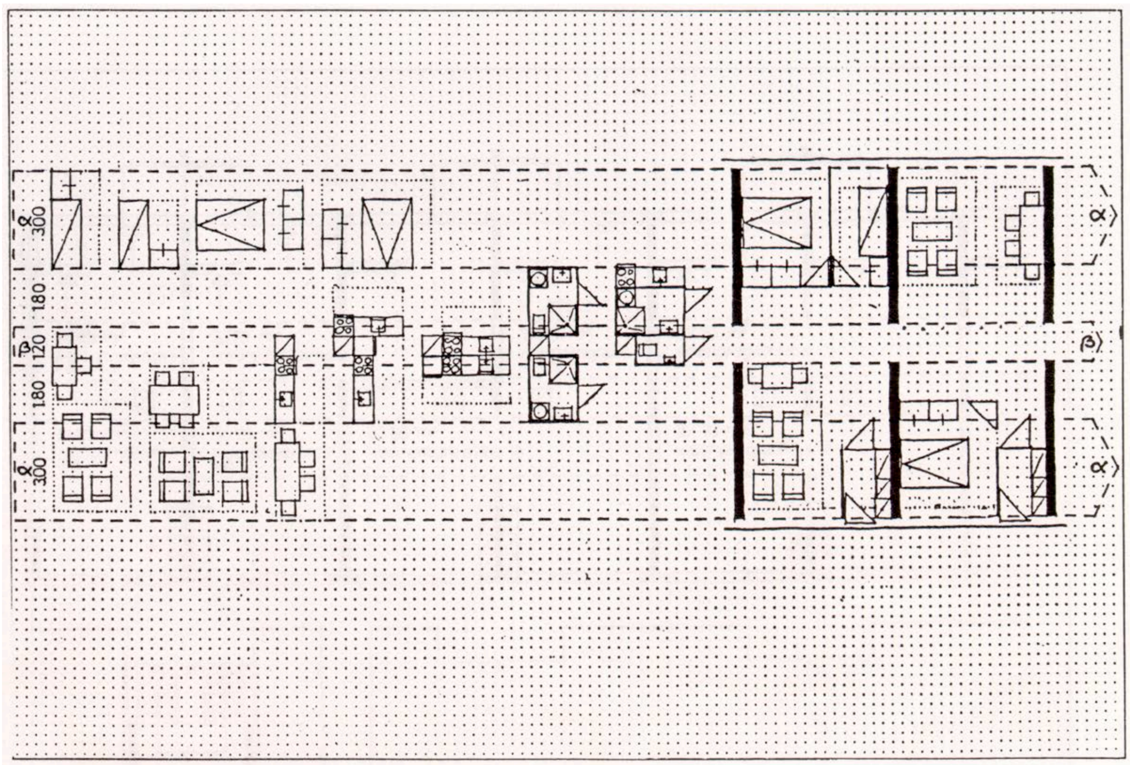


Figure II- 1 This diagram shows the study of capacity analysis in furniture layout level**.** (source: Carp, 1985)

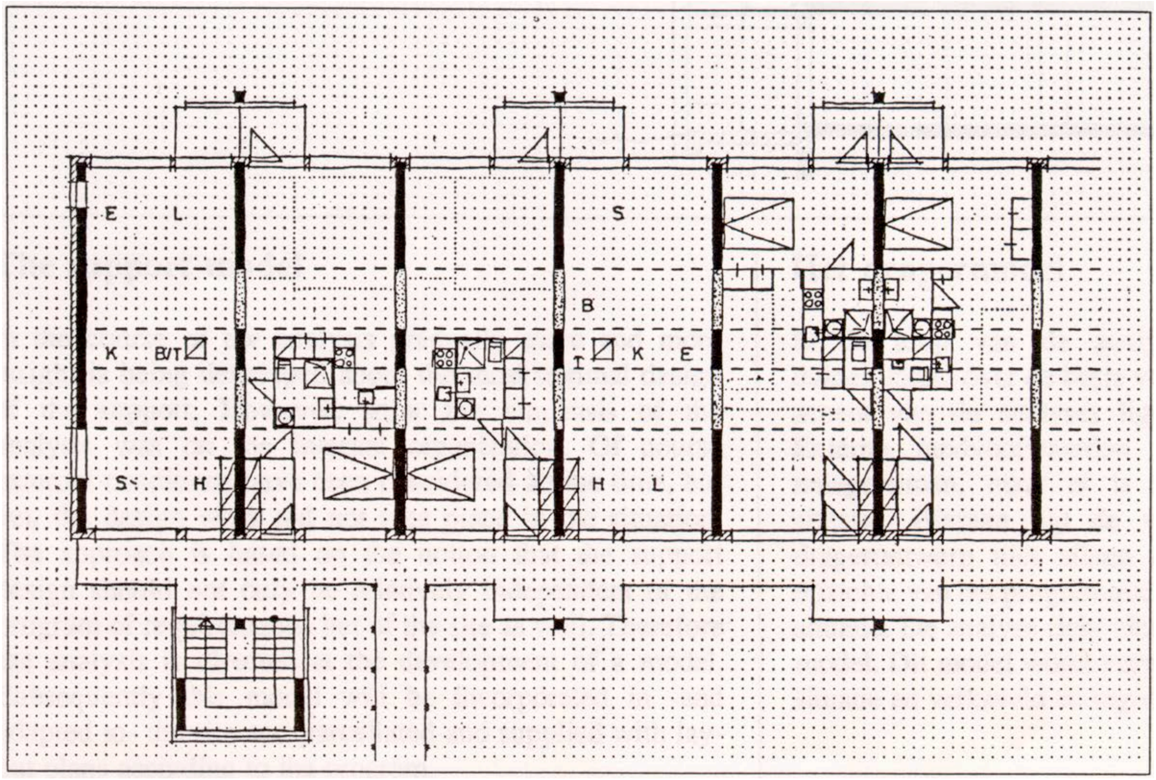


Figure II- 2 This diagram shows the study of capacity analysis in room size level**.** (source: Carp, 1985)

In summary, John Habraken describes the capacity of a house in the following way.

> *"It is characteristic of environmental forms that they invite different patterns of use. We would not be correct saying that the building must 'answer different behaviors'. Doing so, we still want the building to perform. It would be better to say that the house, by its presence as an environment, literally provides space for a range of human activities that we can not all predict, nor exhaustively describe." (Habraken, 1988)*

Given this general overview of capacity analysis, we can now turn to the more detailed discussion of design constraints – why they are needed and how they can be made and used.

II-2 .What are design constraints?

Design constraints are the limitations or rules from the physical world and from the social agreements guiding designers in what they need to do and what they can not do when designing. For instance, we can not design a building which hangs in the air without any supports; nor can we design a 2-foot-wide exit door in a public building. In the first example, the main design constraint is from the physical world: everything has to deal with gravity. The 2-foot-wide exit door is not acceptable because of the building code in the area. Therefore, an architect who is doing a medical building design needs to get information on local medical building codes and rules, and to deal with the physical world based on knowledge – as well as imagination. These are examples of all kinds of rules or guidelines which guide designers during the design process.

Indeed, there are hundreds of design constraints guiding designers when they are designing. According to Habraken, there are two basic kinds of constraints in all design processes.

> *"Firstly, there are always, in a design situation, a large number of implicit constraints that are so obvious to us that we do not bother to formulate them. No one would propose to place the bed in front of the door. This indicates that we always operate in an implicit solution space that is already much smaller than the one bounded by the explicit constraints…*
> *Secondly, the forms subsequently generated will reveal, to those involved in the design process, additional constraints that must be made explicit. …constraints can only come from the consideration of possible – desirable or undesirable – alternatives. Without such alternatives there is nothing to approve of or to reject, and we cannot learn about our values and preferences. (Habrcken, 1988)*

In this thesis, making design constraints for residential floor area design means that efforts are being made to formulate general rules that can assist design teams at the beginning of similar projects. Further case studies – beyond the two in Chapter III - are needed to establish the constraints explained below as being more broadly applicable.

In this thesis, the focus is on multi-story, multi-unit residential buildings, mixed use or not. In all cases, however, an assumption is made that an interface will occur between the residential part of the building and the more public and non-residential part. While most of the constraint development in the thesis is limited to the strictly residential portion of such buildings, the basic question of interface between functional areas (such as between residential and hotel functions as in one of the case studies) as noted here will be briefly discussed later.

II-3 . Studying plumbing constraints is especially important for capacity analysis.

According to Open Building principles, dividing a building into two levels or two steps means also dividing the drainage system into two levels or decisions. All drainage pipes inside an MEP stack are regarded as a part of the Base Building, because they are located in the "public" space, and most of these pipes are vertical pipes serving multiple units. This is equivalent to the city sewer pipes under the street, to which the pipes of each individual house are attached following a set of conventions.

On the other hand, all drainage pipes inside a unit belong to the fit-out, since they are in the fit-out territory. Most of them are horizontal pipes carrying waste water to the drainage pipes located inside MEP stacks. This is quite different from conventional projects where the distinction between “common” and “individual” drainage piping is not made (entanglement) or is not straightforward. In conventional residential high rise buildings, drainage pipes of an individual sanitary fixture penetrate vertically through the building floor at or near each fixture (see Figure II-3 left). During conventional design processes, such penetrations are determined after the layout plan is finished. There are almost no horizontal relations between fixtures in the same dwelling unit, within the served space; instead, fixtures only have relation with other fixtures vertically in different floors. Horizontal drain lines serving fixtures in one dwelling are conventionally hidden in the ceiling of the dwelling unit immediately below (see Figure II-3 right).

As a result, there is usually the same number of penetrations in the floor as there are fixtures. For instance, when there are 20 sanitary fixtures in one floor, it might require 20 penetrations of the floor slab. Therefore, it is no wonder that there are always many dozens of penetrations in a residential high rise building.

After a building is designed and the structure built, plumbing pipes are fixed to and through the concrete floors. It results in a kind of dependency and rigidity among stacked vertical units in conventional high-rise residential buildings. Dwelling units are heavily depending on other floors above and below. Once a typical floor is designed, there is very little freedom to design a significantly different unit layout for other floors because of the vertical drainage piping entanglement.

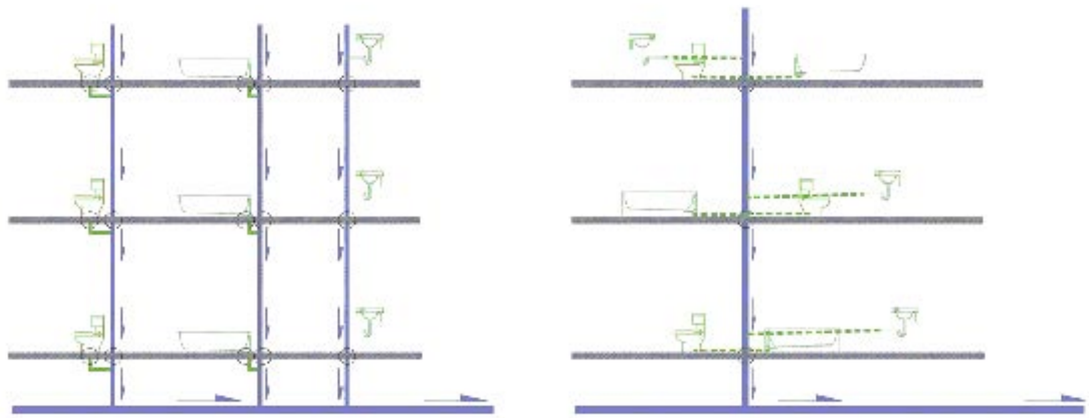


Figure II- 3 This diagram shows the difference in plumbing system between conventional building (on the left) and an Open Building arrangement. There are many penetrations in a conventional building unit, but only one or two penetrations are needed per unit in an OB project

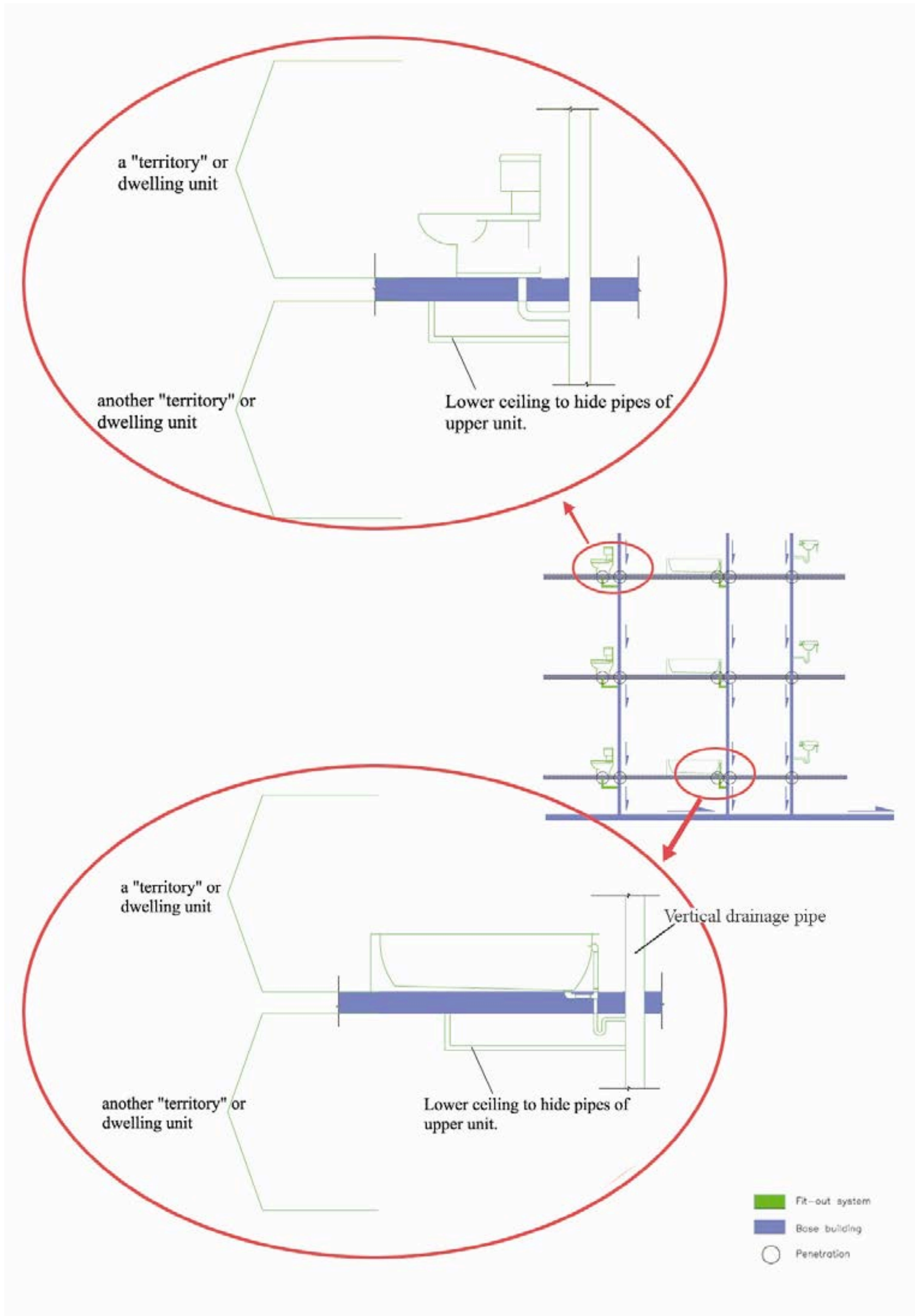


Figure II- 4 Two typical sanitary installations show that drainage pipes penetrate concrete slabs, causing significant limitations on future fixture relocations and causing potential legal disputes when changes are made in one unit and implicate other adjacent units.

Moreover, the entanglement between piping and the building construction causes trouble in at least four ways - from pre-construction to post-construction use.

First of all, for architects, this entanglement causes multiple redesigns before construction begins and the likelihood of change orders later, often without fee compensation unless this is understood when writing the agreement for architectural services. The problem is that layout decisions are interdependent among floors. Once a floor layout is determined (or changed) especially in regard to drainage plumbing, the other floor layouts have to correspond. Without confirming the architectural plan, other consultants such as mechanical and electrical design and even structural engineering can not work independently or efficiently. The excessive interdependency directly causes the design delay and conflict.

Secondly, these plumbing entanglement problems produce high rise residential building designs that can offer only a very few unit plans or mix variations from floor to floor. When a high rise residential building is built, all individual families have to adjust their lifestyles and budgets to the same "uniform" units. Therefore, conventional high rise residential buildings cannot offer variation corresponding to real variation found among individual families, without excessive costs. Of course developers can produce highly varied floor plans but they inevitably cost more and it is never certain that the extra costs can be passed to the renters or buyers who were not consulted.

Thirdly, the entanglement of pipes causes boundary conflicts and even legal disputes between dwelling units. For example, when a toilet pipe of the upper floor is leaking, it causes the inconvenience for the lower floor unit and violates the territorial autonomy. Individual fixture penetrations on the floor can increase the potential of floor leaking issues. In the US, condominiums are well known to be the most legally troubled building type, perhaps due in part to this problem. (Butt, 1993)

Last but not the least, these entanglements cause difficulties for future adaptations. Once a conventional building is built, it is almost impossible to have a bathroom in one floor – thus the floor plan - move to another location or even be enlarged in the same location with additional or upgraded fixtures and layouts. There are two reasons contributing to this impossibility. Firstly, drainage pipes are fixed into sleeves in the floors (concrete slabs or wood – framed floors are the same in this regard), and the vertical pipes still need to be kept because they are not only draining one floor but also the upper and lower floors; secondly, there are no vertical plumbing pipes that can carry waste water from sanitary fixtures in the new locations. Adding a penetration would affect all the units above and below the unit in question.

II-4．The study of DWV systems in an Open Building strategy

Drainage piping (DWV or drain, waste, vent) is more difficult than other plumbing or other "mechanical" or "installation" systems in housing, such as cabling or water supply systems. In residential DWV systems, waste is carried via water by means of gravity, but in electrical systems, gravity does not apply. Even in water supply systems, piping has more freedom because they are smaller and piping pressure enables supply lines to be routed independent of gravity.

There are several design restrictions in designing residential DWV systems especially in O.B. projects. Dividing the plumbing system into two levels requires knowledge and design constraints in guiding how to operate, and for connecting the fit-out parts to the base building parts.

To accomplish this goal, initially, some fundamental rules are set as part of an OB strategy, some building codes are applied and some conventional practices are assumed as evaluation criteria. Accordingly, this study uses the following criteria:

1. *Horizontal drainage pipes slope @ 1/8" per foot. (UPC,2003)*
2. *All sanitary fixtures are above floor rough-in. (OB principle)*
3. *All horizontal drainage pipes go into fit-out partition walls. (OB principle)*
4. *All waste water discharges into vertical MEP stacks inside the territorial unit (OB principle)*
5. *There are no other penetrations except MEP stack openings. (OB principle)*
6. *The use of code-approved "air-admittance valves" is assumed for all plumbing fixtures (except toilets)*
7. *All products must be available in the U.S market. (conventional practice)*

Regarding the first rule, current U.S building codes require that drain lines slope at 1/8" per foot. This code has not been changed for decades.

An additional constraint should be noted. In conventional DWV installations, horizontal drainage piping from a given dwelling is placed in a lowered ceiling of the unit below. This violates an important OB rule. In an OB project, horizontal drain lines must remain inside the dwelling unit they serve. One of the consequences is that no drain line may cross a doorway on its route from the fixture to the MEP stack. This constraint is assumed in the discussion that follows.

II-5 . Fixture description and study

There are typically eight fixture types in a residential dwelling unit producing waste water. These fixtures are HVAC, water heater, washer, sink, toilet, bath-tub, and shower-tub. In the following sections, individual fixtures are described and analyzed for the purpose of developing OB design constraints.

II-5-a Toilet

There are two kinds of flush systems in toilets. One is a pressure-assisted flush system and the other is a gravity-flush system. The former is usually used in transportation vehicles or facilities with a lack of water, or in installations where water conservation is important for reasons of economy or water scarcity. Increasing numbers of toilets in commercial establishments use pressure assisted toilets. Because the gravity-flush system requires less maintenance than the former, it is widely used in most buildings, especially in residential buildings. It uses the water's weight to generate flushing pressure. The pressure brings solid material from the bowl and through the S-shaped trap to the drain pipe. A siphoning action completes the flush.

The second distinction in toilets is the direction of the outlet. The conventional type in residential and many other applications is the downward outlet (figure II-5-a). This kind is floor mounted. The other type is rear discharge. This is available in wall-hung and floor-mounted versions. The wall mounted rear discharge type is familiar in institutions, public facilities and other situations were maintenance personnel like the absence of obstructions to cleaning the floors (figuresII-5-b). Finally, we have the floor mounted rear discharge type (figure II-6)

Figure II- 5

Figure II- 5-a Gravity-flash system toilet working diagram. This kind of toilet can not be applied in O.B. project, because the opening of the discharge outlet requires floor penetration.

(Source: http://www.us.kohler.com/onlinecatalog/pdf/1113804_6.pdf)

Figure II-5-b. The wall mounted rear discharge type toilet

(Source: http://www.us.kohler.com/onlinecatalog)

The toilet shown in Figure II-5-a can not be applied in an O.B. installation because its waste outlet opens directly into the floor. It does not meet one of the criteria set before. The exception to this rule is the use of a raised fit-out floor, under which horizontal drainage piping can be installed. This thesis does not utilize this approach. Further studies are needed using the raised floor strategy. (Other studies are also needed using a wall-mounted rear discharge toilet) (See FigureII-5-b)

For the floor – mounted rear discharge type (Figure II-6), the height of the outlet above the floor - 4" – is an important dimension, because it presents constraints in deciding the distance from the toilet to an MEP stack and also the interrelations within a partition wall, as the following sections show.

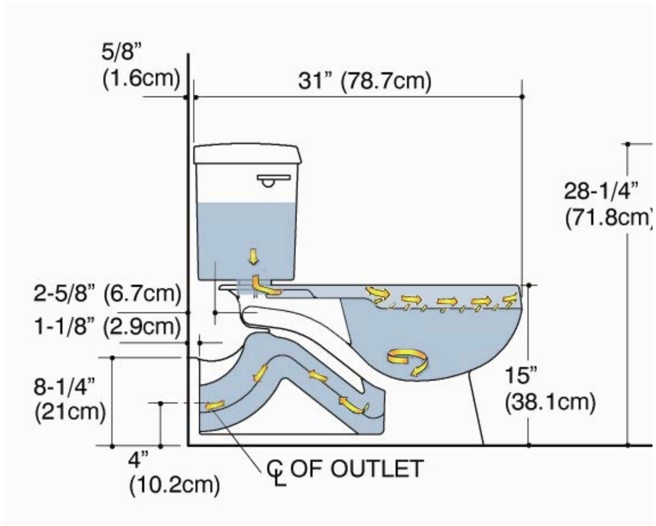


Figure II- 6. Toilet product with its outlet 4" above floor rough-in fit for O.B. This kind is available from several companies distributing their products in the US market, e.g. Kohler …etc.

(Source: http://www.us.kohler.com/onlinecatalog/pdf/1020805_4.pdf)

II-5-b Bath-tub and Shower-tub

Similarly, water is used in bath-tubs and shower-tubs, and drained out by means of gravity. The water outlet of a tub should be located on the bottom to be able to evacuate all water that a tub contains. This causes difficulties in installing bath-tubs or shower-tubs in an O.B. way because there is no space for a horizontal pipe under the tub or shower, set at conventional elevations, to have enough slope to the main vertical drainage pipe in the MEP stack. The only way to solve the problem is to raise the tub up to get a reasonable height to slope the drainage pipe above the floor.

According to research of products on the market conducted for this thesis, there are basically two kinds of drain installations for bath-tubs. One is the conventional way for bath drain installation, in which a vertical pipe penetrates the floor at the fixture, therefore violating a key O.B. requirement (FigureII-7 left and FigureII-8). The second is called a “back-outlet” type, for bath drain installation. It drains water horizontally without a floor slab penetration at the fixture. It can be applied in O.B. installations more easily (FigureII-7 right and Figure 9)

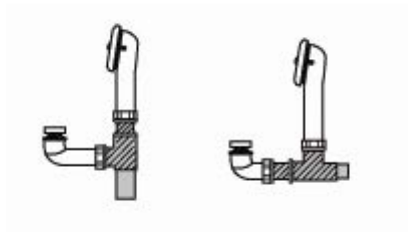


Figure II- 7 The left type is a conventional way for bath drain installation; it requires floor penetration at the fixture, therefore, can not be used in an O.B. installation. The right type is a back-outlet drain installation; it can be used in O.B**.**

(Source: http://www.us.kohler.com/onlinecatalog/pdf/089407_4.pdf)

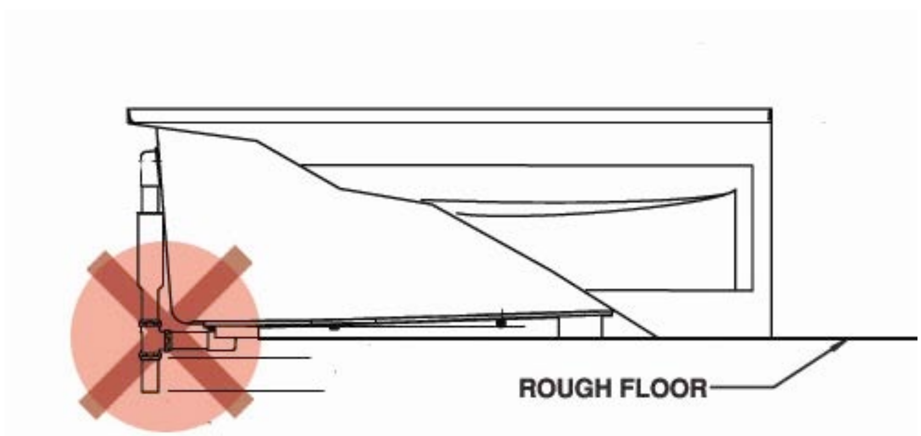


Figure II- 8 The conventional way for bath drain installation in which the vertical drainage pipe penetrates the floor.

(Source: http://www.us.kohler.com/onlinecatalog/pdf/089506_4.pdf)

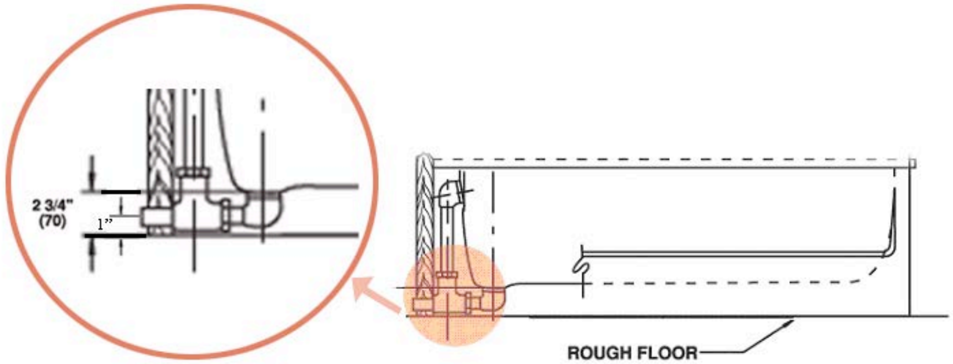


Figure II- 9 The back-outlet way for drain installation in which no floor penetrations is needed at the fixture.

(Source: http://www.us.kohler.com/onlinecatalog/pdf/068403_4.pdf)

The back-outlet drain installation of the bath-tub and shower base is selected for use in this study However; this does not fully solve the problem. A further adjustment from conventional practice is needed.

Connecting to the horizontal pipe is a U-trap and an additional horizontal drain line which – using a standard trap - requires 5” minimum vertical dimension from the rough floor. Further, this horizontal pipe requires the code mandated slope of 1/8” per foot. However, there is only about 1 ¼” spacing between the water outlet and the floor in the back-outlet tub or shower installation, far less than 5” required for the trap. Since the floor can not be penetrated, one solution is to raise the tub 5” to get enough space. FigureII-16 shows that after the bath-tub is raised that there is enough space for a U-trap to connect the horizontal drain pipe above the floor, and the horizontal pipe is high enough to get slope to a nearby MEP stack.

This approach allows the bath-tub or shower-base to be placed about 24’ – 0” from an MEP stack. This raises the height for a bath-tub lip to approximately 19”. If needed, as in a whirlpool installation - a step can be placed before the bath-tub or shower for easy accessibility. (See Figure II-10)

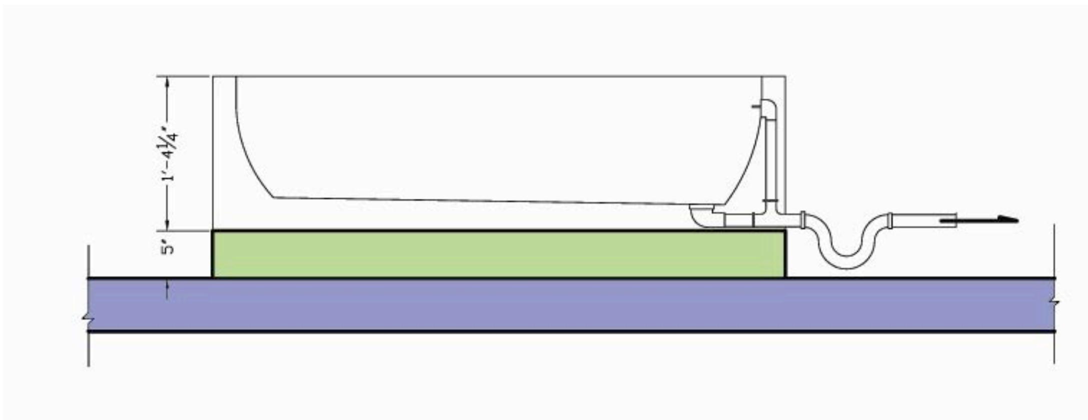


Figure II- 10. The bath-tub is raised up 5" to get enough space to install a U-trap and correct slope to the plumbing stack nearby.

II-5-c Sink, lavatory and washer

Water outlets of sinks, lavatories and washers are about 14" to 20" above floor (except the washing machine whose drain connection is often at 36" above the floor). Similar to other waste drainage fixtures, a U-trap is required between the fixture and the horizontal pipe leading to the MEP stack. U-traps and pipes are usually installed right below sinks and lavatories and hidden inside cabinets (or inside walls). Using the slope ratio 1/8" per foot, these fixtures can be placed up to 112' away a MEP stack when the water outlet is 14" high! However, in a typical unit, a distance of 40 feet (drainage line length) from a MEP stack is long enough for freely placing a fixture. For systematic issue and standard installation, a range is given for sinks, lavatories and washers to get slope, this range is 10" to 15" above floor; below or above this range high, and drainage pipes should go in perfect vertical angle.

Figure II- 11 photograph of a typical family kitchen sink.

(source: http://www.us.kohler.com/onlinecatalog)

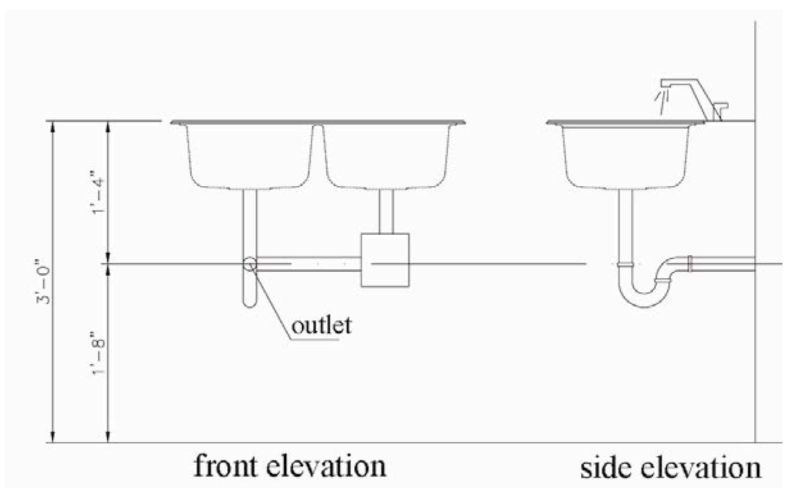


Figure II- 12 . This diagrams show technical figures of sink and lavatory. (These drawings show the relation of the fixture to the trap and drain line outlet)

II-5-d HVAC and water heater

In high-rise residential buildings, HVAC units and water heaters are often placed above the ceiling or in the upper parts of storage closets, to save floor space and provide easier distribution of conditioned air and heated water. The quantity of waste water from the HVAC unit and water heater (basically emergency overflow and condensate water) is far less than other fixtures. Because HVAC and water heaters can be placed in high positions, drainage pipes from them can simply drop down and join a horizontal pipe below.

II-6 Zoning fixtures in vertical dimension

Based on the height from discharge outlets to the floor, these eight fixture types can be sorted into three categories corresponding to three horizontal "positioning" or "routing" zones (see table II-1). HVAC and water heater are often hanging above ceilings (at least in buildings with large floor to ceiling dimensions); they belong to Ceiling Drain Zone (CDZ); washer and sinks have their water outlets around 14"-20" above the floor; they belong to Higher Drain Zone (HDZ). Toilets bathtubs and shower-tubs have their waste water outlets less than 5" from the floor; they belong to Lower Drain Zone (LDZ) (See Figure II-13).

	Lower Drain Zone (LDZ) sanitary fixture	**Higher Drain Zone (HDZ) sanitary fixture**	**Ceiling Drain Zone (CDZ) sanitary fixture**
Fixture drains Gray water	Shower-tub, Bath-tub, toilet	lavatory, washer, dryer Sink, dishwasher	HVAC, water heater

Table II-1

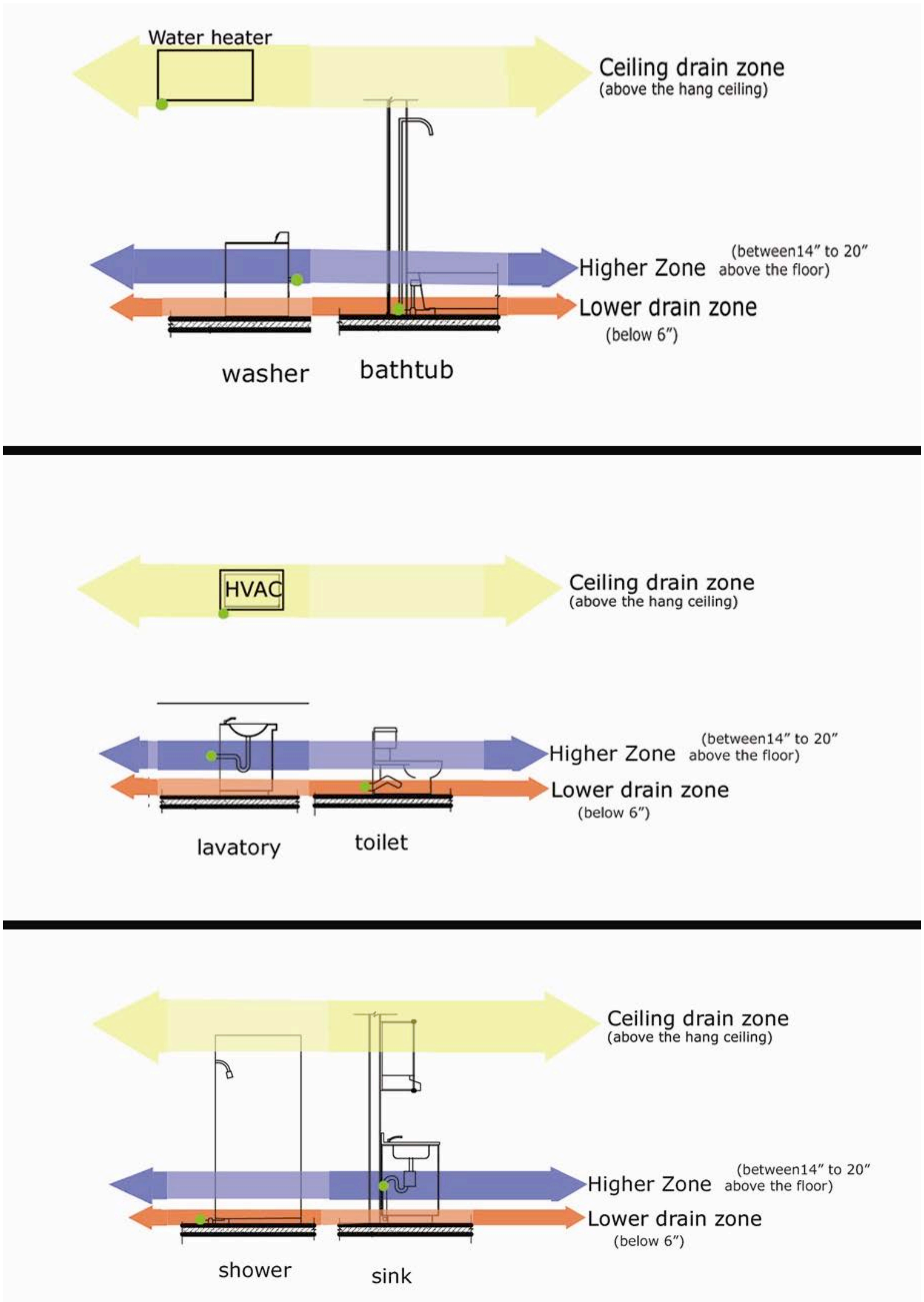


Figure II- 13 Based on the water outlet high of each fixture, three kinds of fixtures are categorized: Lower Drain Zone (red), Higher Drain Zone (blue) and Ceiling Drain Zone (yellow). Green spots indicate fixture outlets.

For those fixtures belonging to the Ceiling Drain Zone and Higher Drain Zone, there is enough height to let drainage pipes slope horizontally and reach main drainage pipes inside MEP stacks up to a distance of 80 ft. which is long enough to place a fixture anywhere inside a unit. However, fixtures belonging to Lower Drain Zone present more difficulties in discharging waste to the vertical MEP stack using above-floor pipes. These sanitary fixtures are toilet, bath-tub and shower-tub.

Research in this thesis has paid attention to these three zones and focused most attention on the Lower Drain Zone fixtures because they are the main cause of building entanglement. Research looked for available products and their characteristics; and studies are mainly analyzing the relations among sanitary fixtures, partition walls and MEP stacks. The results of the study of the LDZ are used in the demonstration in Chapter Three.

II-7 Partitions carrying horizontal drain lines

In an Open Building fit-out installation, all waste water from each sanitary fixture goes through horizontal drain pipes (part of the fit-out product bundle) to a vertical drain pipe located in an MEP stack (part of the Base Building installation). For reasons of appearance, these horizontal drain pipes in the fit-out level are placed inside partition walls. In addition, wiring such as electricity, digital cable, phone line and other wires go inside partitions and above dropped ceilings. Partitions in residential units are already very full of piping, wiring and ducts. In an OB installation, it is critical that these MEP lines be very carefully organized.

The following partition wall study was done as part of the thesis. The goal is to design a partition wall system that applies in Open Buildings fit-out installations, that is

a) capable of carrying piping and wiring;

b) can contribute to off-site kiting and on-site installation (not part of this thesis) but also

c) Makes future reconfigurations less costly and wasteful than today's methods.

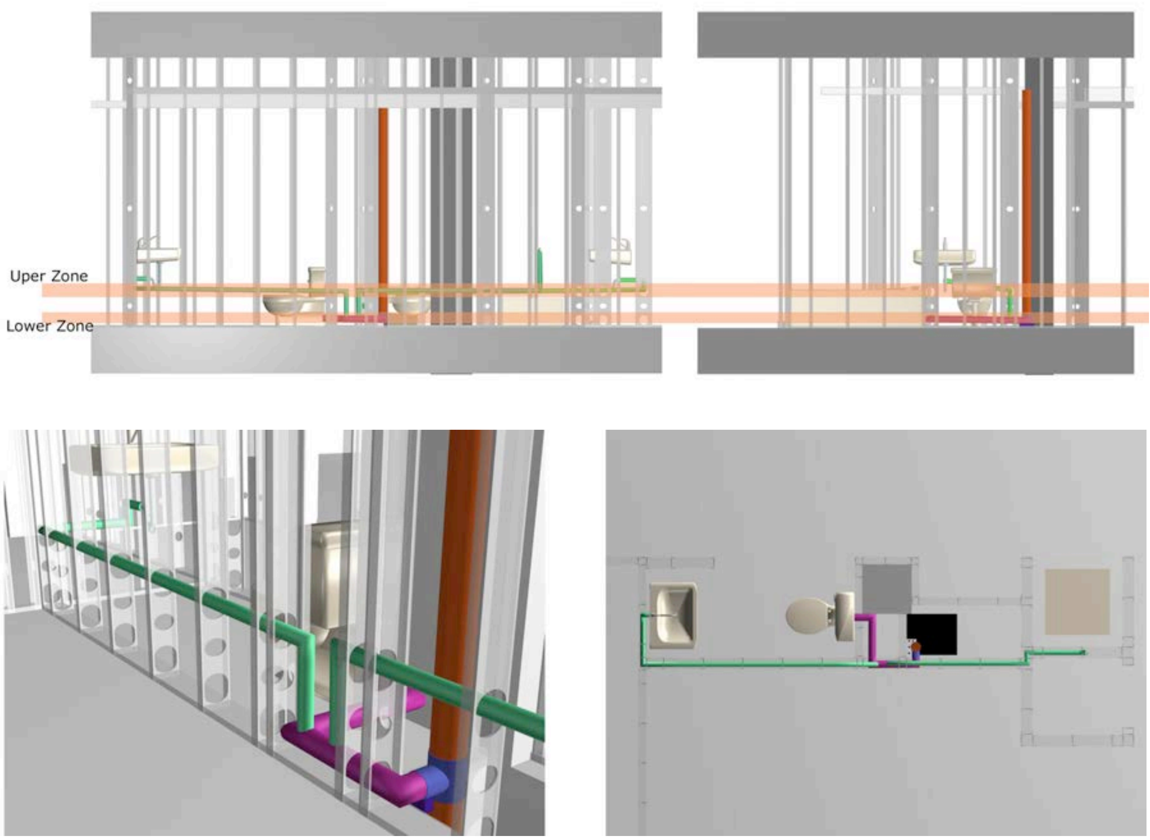


Figure II- 14. These diagrams use a digital model to help design the partition wall. In these diagrams, openings on studs are created. Studs are placed in simulative real mode. Green pipes represent 1 1/2" or 2" diameter drainage pipes serving for HDZ fixtures. They run through the higher opening. Purple pipes represent 3" diameter drainage pipes which serve toilets and accept waste from green pipes. Dark brown pipes are vertical 5" diameter drainage pipes that belong to the Base Building, gathering waste from each dwelling unit and transporting the waste to the city drainage system. Left below diagram shows the 3-dimensional relation in detail.

Fit-out partition walls with MEP carrying capability are interior non-bearing steel frame walls that separate different functional spaces inside a unit. These do not include the demising wall between dwellings.

These walls consist of studs aligning on tracks as the frame, and drywall gypsum boards attaching to the studs as the skin. Normally, in conventional partition walls, there are several openings in the studs for horizontal channel bracing. Wiring and piping run somewhat randomly through the openings. The openings are pre-punched and several models are available on the market. In this dynamic market, some manufactures offer customized punching for customers' special needs. Since there is already a service available in the market, what it needed is to have a good decision regarding the position and dimension of openings.

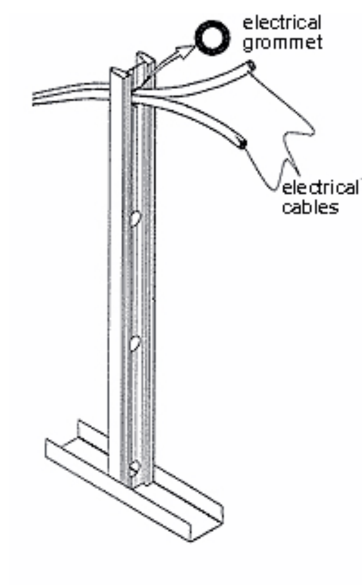
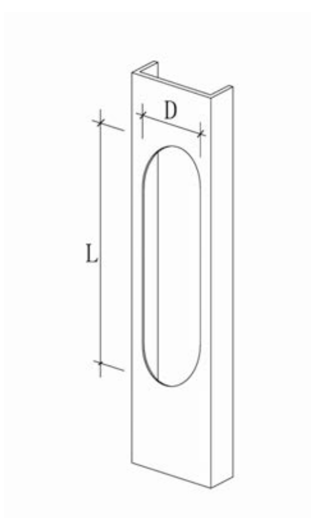
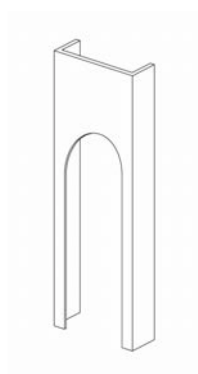


Figure II- 15. This is a customized pre-punched stud in which opening are used for organizing cables inside stud walls for the customers' special requirements.

(source: http://www.customstud.com/pdfs/productlisting.PDF)

In the two case studies in Chapter 3, not only wiring, but also drainage pipes and water supply piping go into the partition walls. Therefore, it is important to have well located and dimensioned openings in studs to carefully organize the “traffic” consisting of water drain-pipes, supply lines and wiring inside the partition walls. As shown in FigureII-13, all fixtures producing waste water can be categorized in three zones based on their outlet height. Therefore, there are should be at least three openings located in each “stud zone”, large enough for drainage pipes to pass through and high enough to get the necessary slope inside the wall to reach the MEP stack. Thus, the dimension of “D” and “L” (see Figure II 16-a) of each opening is to be determined. As known, 5 1/2” studs are widely used as framing for partition walls. Including 1/2” gypsum board in both sides, the partition wall is 6 1/2” thick. 3 1/2” studs are also used to accommodate smaller pipes and wiring.





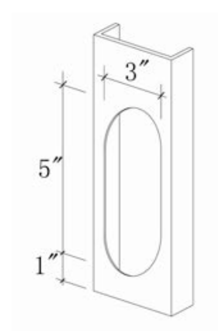


Figure II- 16

Figure 16-a **Figure 16-b** **Figure 16-c**

Usually, toilet discharge pipes are 3” in diameter and other pipes are 1 1/2” or 2”. Toilet pipes (and drains from bath and shower tubs) are running in the Lower Zone. Therefore, the dimension “D” of Lower Zone should be 3 1/2” width (in a 5 1/2” stud). On the other hand, “D” in Higher Zone and Ceiling Zone should be 2 1/2”.

The following considerations are used to determine the dimension “L” in each opening. It is easy to determine in Higher Zone and Ceiling Zone, because when the “L” is 6”, the opening can accommodate any fixture 48’ away from an MEP stack. This distance is long enough for a plumbing fixture to be placed anywhere in a unit as long as it is connected to the vertical stack by a Fit-out wall.

However, the most difficult technical solution is in determining the dimension of “L” in the Lower Drain Zone. The point is to increase the distances of LDZ fixtures to any given MEP stack to achieve more space layout variability, while adhering to the rule that drain lines will not cross a door opening. Figure16-b may be an ideal opening. However, it greatly decreases the strength of studs. In order to obtain studs with appropriate strength without increasing the steel “gauge”, the opening cannot extend to the bottom of a stud. As a result, the opening for the LDZ should be as shown in Figure16-c, and combined with the HDZ opening, a stud will be as shown in Figure II-17.

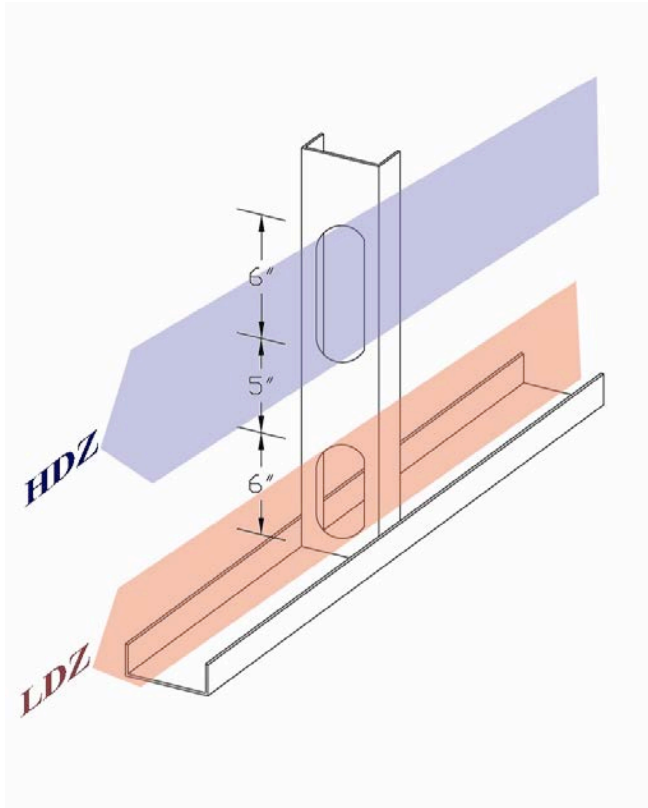


Figure II- 17 The ideal stud design to accommodate both the LDZ and HDZ drain lines.

II-8 Organizing piping "traffic" inside partition walls

After determining the openings in studs, a full description is possible regarding the organization of drain pipes inside the partition walls in different circumstances. It can help in designing better bathroom and kitchen layouts in which fixtures are given appropriate locations.

II-8-a Adding extra wall to solve LDZ fixture "problems"

During the development of these design constraints, difficulties and problems always occurred in the LDZ zone. One of the difficulties is solving piping connections in the LDZ zone. For HDZ and CDZ, vertical drainage pipes from fixtures can simply drop down to connect with the horizontal pipe below at an appropriate angle (See Figure II-18).

However, situations in the LDZ zone are different, because LDZ fixtures are only 1" to 2" higher than the LDZ horizontal discharge pipe. Therefore, angles from a LDZ fixture to a horizontal drainage pipe vary depending on the fixture's location. (See Figure II-19) The various angles and elevations are only predictable within a range. In order to give order to these conditions, an O.B. constraint is set for LDZ piping as follows: In LDZ, there will be an extra wall when drainage pipes from two LDZ fixtures discharge into the same partition wall. One consequence of this is that there must be two vertical drain pipes inside a MEP stack to accommodate LDZ discharge pipes.

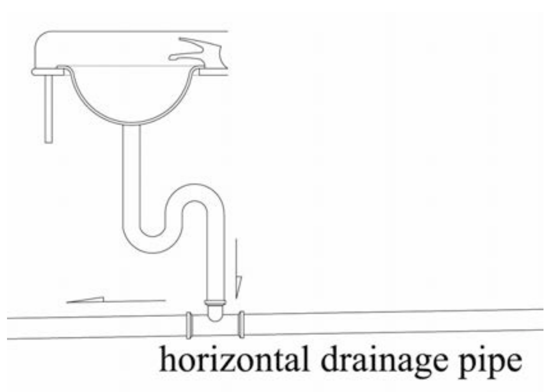


Figure II- 18. HDZ and CDZ fixtures connect a horizontal drainage pipe at right angles.

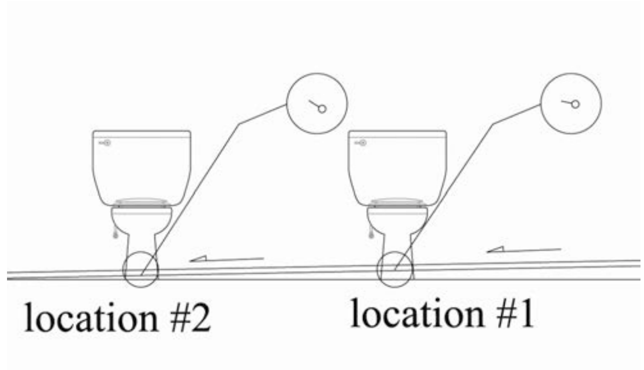


Figure II- 19. When a toilet connects to a sloping horizontal drainage pipe in different locations along its slope, it creates various angles. This requires independent drainage pipe for each LDZ fixture.

II-8-b Organizing drainage piping inside one bathroom

The following is a demonstration of relations between bathroom fixtures and an MEP stack. Three typical bathroom layouts are given in order to describe a series of technical rules in organizing the "traffic" inside partition walls to satisfy the O.B. criteria. It is obvious that the study here focuses on fixture distances to a MEP stack and fixture arrangements in a bathroom.

In Figure II-20-a, a toilet and a bathtub discharge into the same partition wall, and the toilet is closer to the MEP stack. Because toilet and bathtub belong to the LDZ zone, both of their drain pipes go through the LDZ opening in the stud. Moreover, they need to be separated in two drain pipes, because toilet drains black water and bathtub drains gray water. Therefore, an additional "fit-out" wall is needed, to allow each drain pipe its own route to the MEP stack without interruption or collision.

The question of how to decide which pipe goes through which partition wall needs to be answered. In order to get more useful floor space, additional wall thickness should be minimized. To approach this goal, another constraint is set: when toilet and other LDZ fixtures share one partition wall to route drain pipes to the same MEP stack, the discharge pipe of the fixture closer to the MEP stack drains goes through the additional wall. As shown in FigureII-20-a, toilet and bathtub share the same partition wall in draining, while the toilet is closer to the MEP stack. According to the draining rule, one additional wall is attached to the partition wall between the toilet and the MEP stack. Similarly, in Figure II-20-b, one additional wall is attached but for bathtub to drain because bathtub is closer to the MEP stack than the toilet. However, in Figure II-20-c, the toilet and bathtub are using different partition walls to drain. The "extra wall" constraint does not apply to this circumstance.

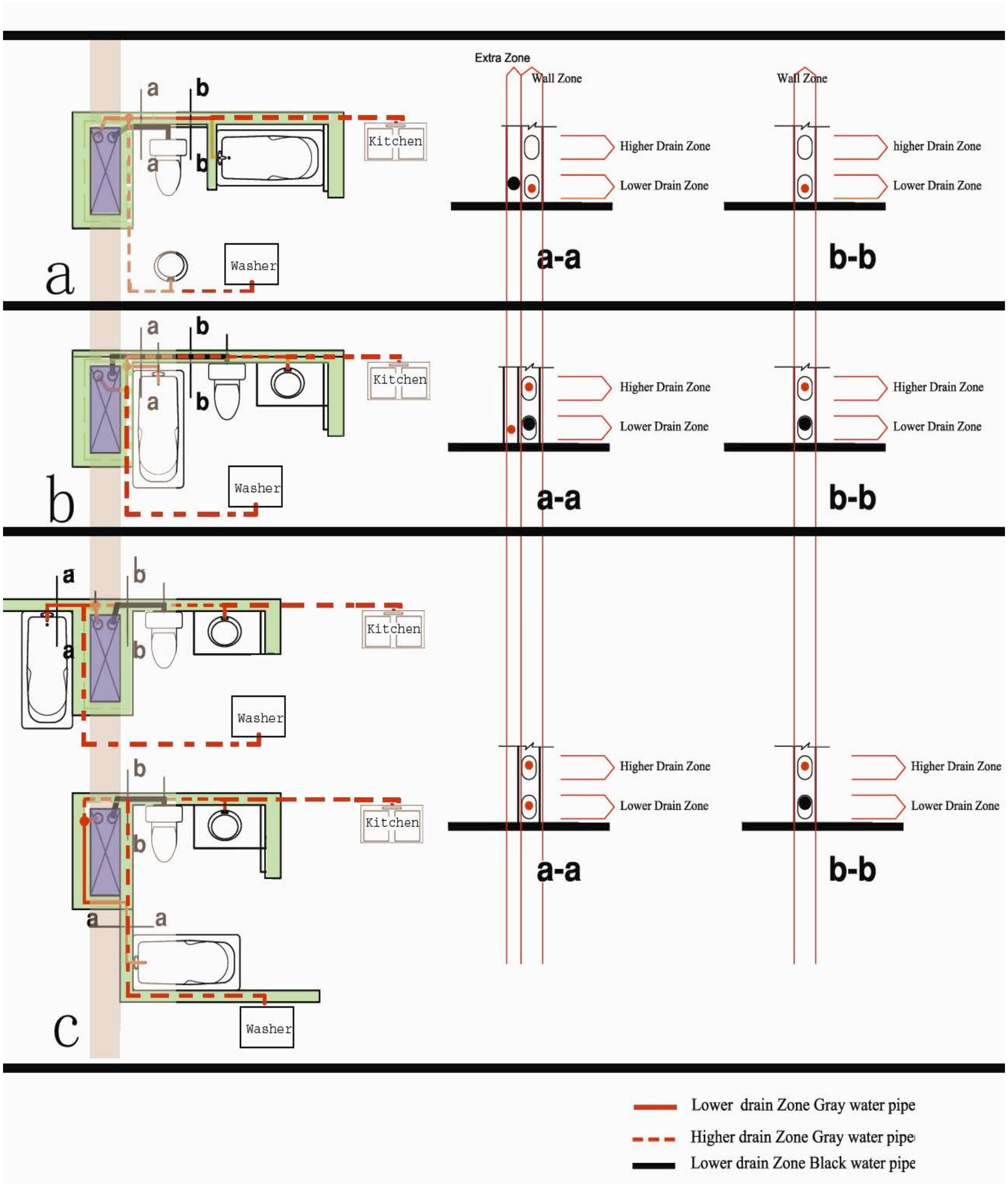


Figure II- 20 These examples are taken from the first case study (the Kales Building Conversion project). See Page 87.

II-8-c Organizing piping in a circumstance where two bathrooms share one MEP stack

In an O.B. project, it is more likely to have two bathrooms sharing one MEP stack. Additionally, sometimes two bathrooms together with a kitchen are sharing one MEP stack. For instance, in the second case study which is a high-rise multi-story condominium with luxury standard requirements, there are normally three to four bathrooms/ half-bathrooms in one unit. As a result, two bathrooms and other utility rooms sharing one MEP stack can be found in many variations. The difficulty is not in Higher Drain Zone (HDZ) fixtures; but always in dealing with Lower Drain Zone (LDZ) fixtures. The more LDZ fixtures, the more complicated the drain system would be.

The following is another example taken from the second case study, the intent of this example is to demonstrate how to organize drainage pipes when two bathrooms and one kitchen share one MEP stack (Figure II-21).

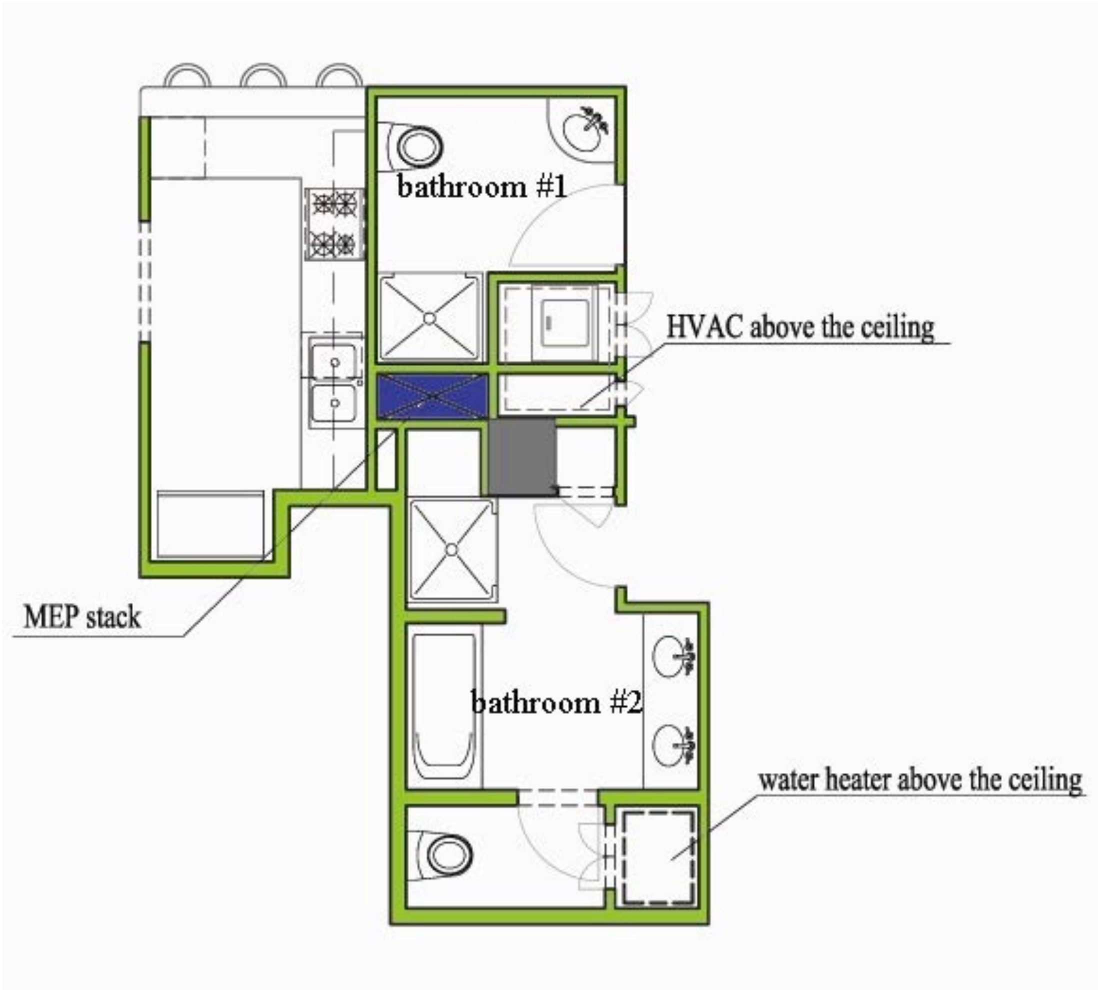


Figure II- 21 This example is taken from a layout variation from the second case study. In this example, two bathrooms, one kitchen, one laundry room and other utility fixtures such as water heater and HVAC are sharing one MEP stack which causing more constraints in organizing the piping "traffic" inside the partition walls.

In this example, thirteen fixtures drain to one MEP stack, located between two bathrooms and adjacent to a kitchen. These fixtures are three lavatories, two shower-tubs, two toilets, one bath-tub, one kitchen sink, one washer, one HAVC unit and one water heater.

According to Table-1, these thirteen fixtures can be distributed to three zones. The first are

LDZ fixtures, in this example, which include two shower-tubs, one bath-tub and two toilets; the second groups are HDZ fixtures, which include three lavatories, one kitchen sink, and one washing machine. The last group includes CDZ fixtures, which are the HVAC unit and the water heater.

The following study is a step-by-step process in arranging and organizing the piping "traffic" inside partition walls in this situation. Basically, there are three steps.

First of all, the priority is to deal with the LDZ fixtures that are the most distant from the MEP stack in each bathroom. In bathroom #1, the toilet is an LDZ fixture, and has the longest distance to the plumbing stack. It is marked as red L.F. (stands for low and far) in Figure II-22. Similarly, in bathroom #2, another toilet is marked as red L.F. because it also has the longest distance to the plumbing stack. According to the former study, (see Page 48) the drain pipes of L.F. fixtures can go through partition walls to reach the plumbing stack (see Figure II-23 and Figure II-24).

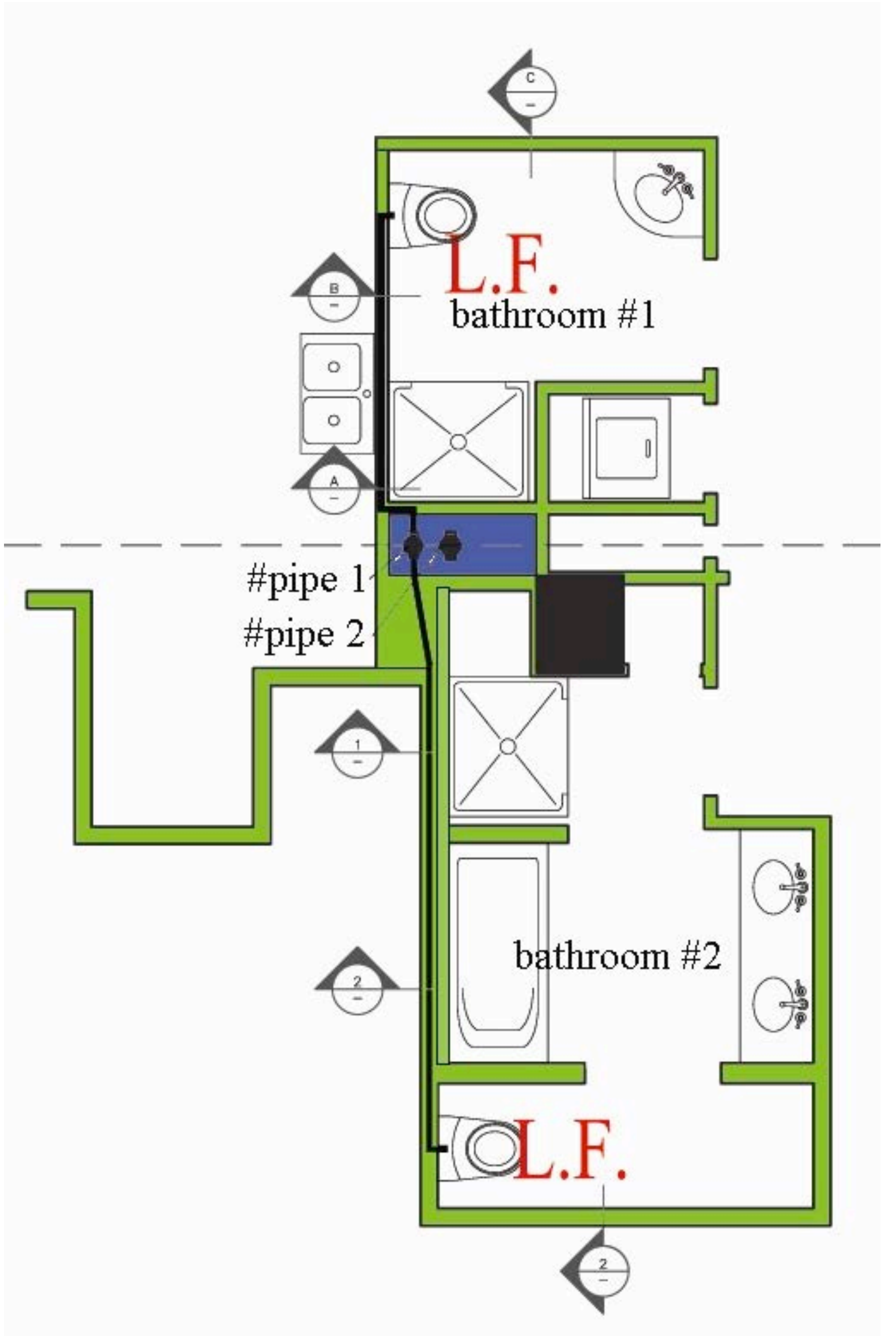


Figure II- 22. This diagram shows the first step in organizing piping inside partition wall. Two toilets indicated "L.F" are firstly connected to MEP stack.

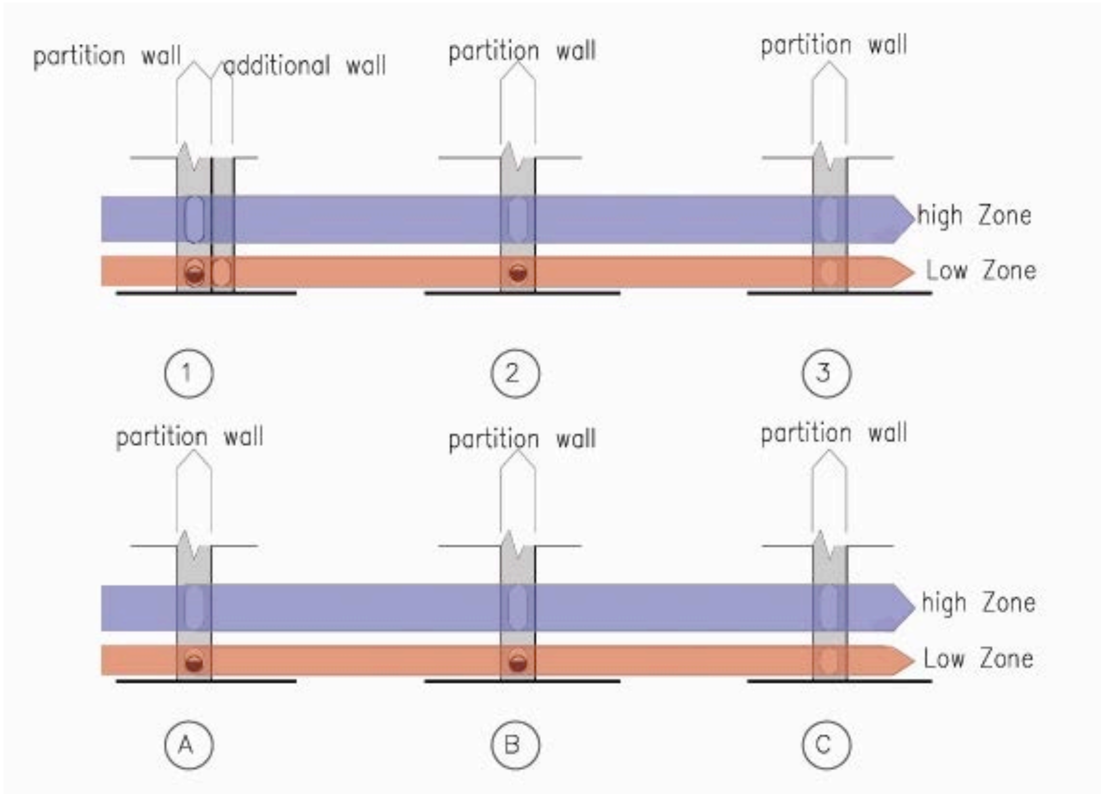


Figure II- 23

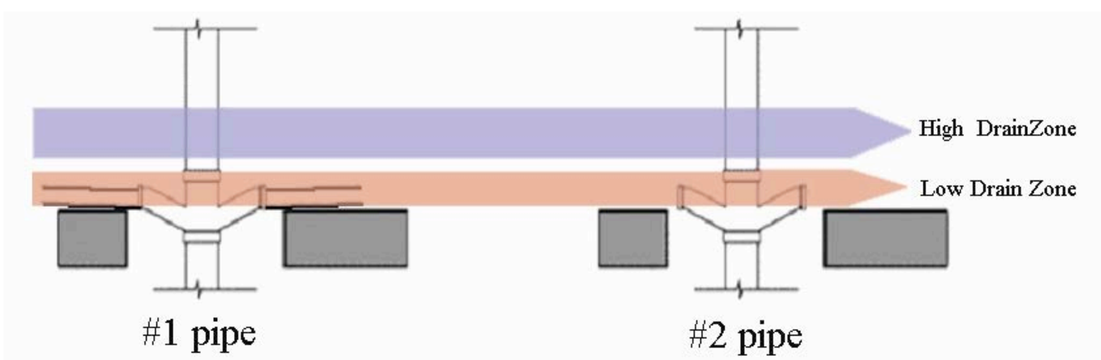


Figure II- 24

Secondly, after dealing with the LDZ fixtures furthest from the MEP Stack, the next step is to deal with the rest of the LDZ fixtures (they are marked as red "L.N." in Figure II-25). In bathroom #1, according to the rule from a previous study (see P48), because the shower-tub and the toilet are sharing two different partition walls, the toilet can drain to the plumbing stack through a parallel partition wall. In bathroom 2, because a shower-tub and a bathtub are sharing the same partition wall with the toilet, the shower-tub and the bathtub drain to the MEP stack through an additional wall zone which is adjacent to the other partition wall. (See Figure II-26 and Figure II-27)

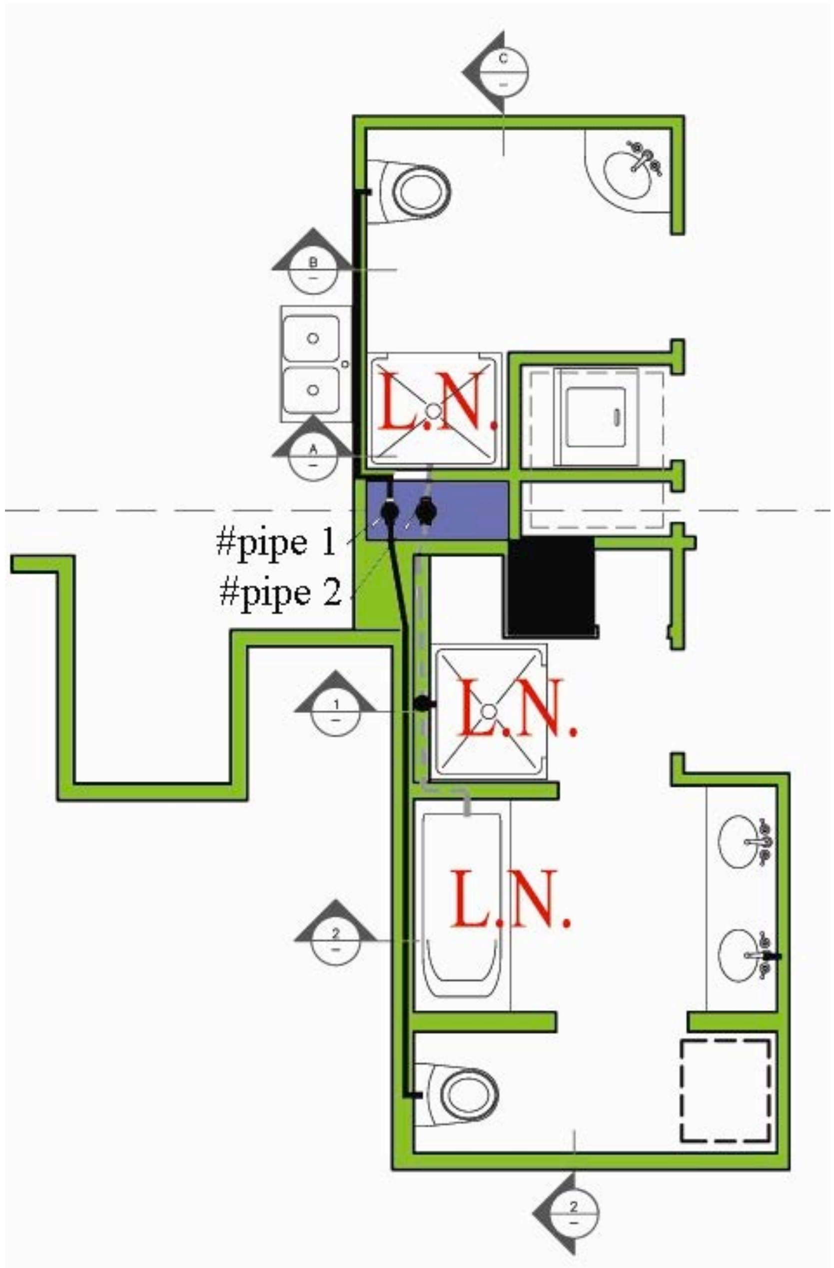


Figure II- 25 This diagram shows the second step in organizing piping inside partition wall which is to deal with the rest fixtures belong to LDZ. In this diagram, they are labeled as “L.N.”.

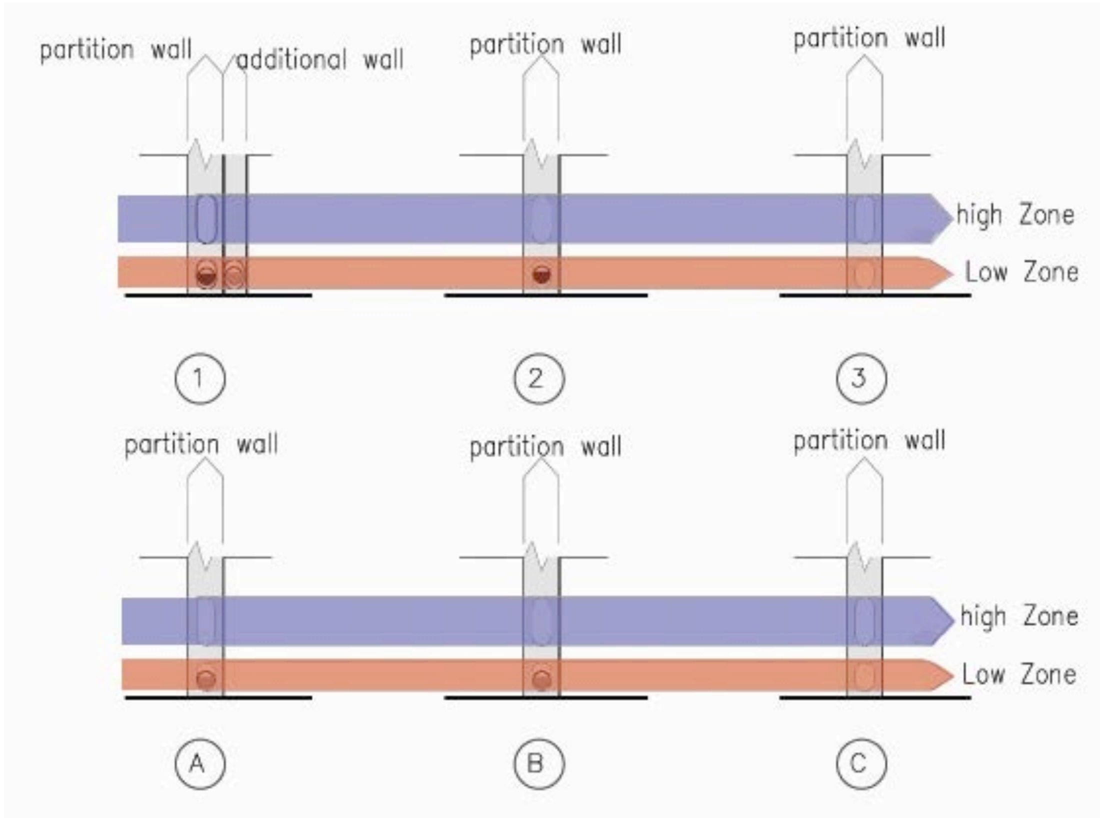


Figure II- 26

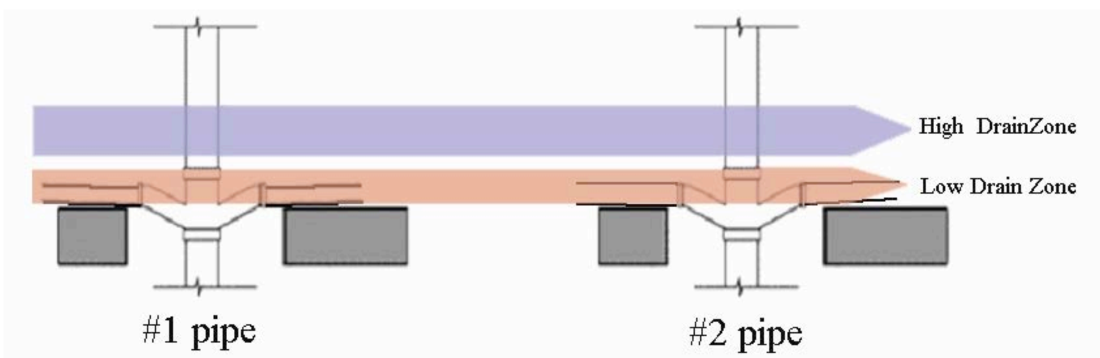


Figure II- 27

The last step is to deal with those fixtures belonging to HDZ and CDZ zones (they are marked as red "H." and "C.H." in Figure II-28). HDZ fixtures are the kitchen sink, bathroom lavatories, and washer. CDZ fixtures are the water heater and the HVAC unit. HDZ and CDZ fixtures drain gray water and have their water discharge outlets in higher positions. Technically, there is less difficulty in connecting their pipes to the MEP stack. Waste discharge pipes from each HDZ and CDZ can simply drop drown to connect to a horizontal pipe running below in the previously discussed walls. . (See Figure II-29 and Figure II-30)

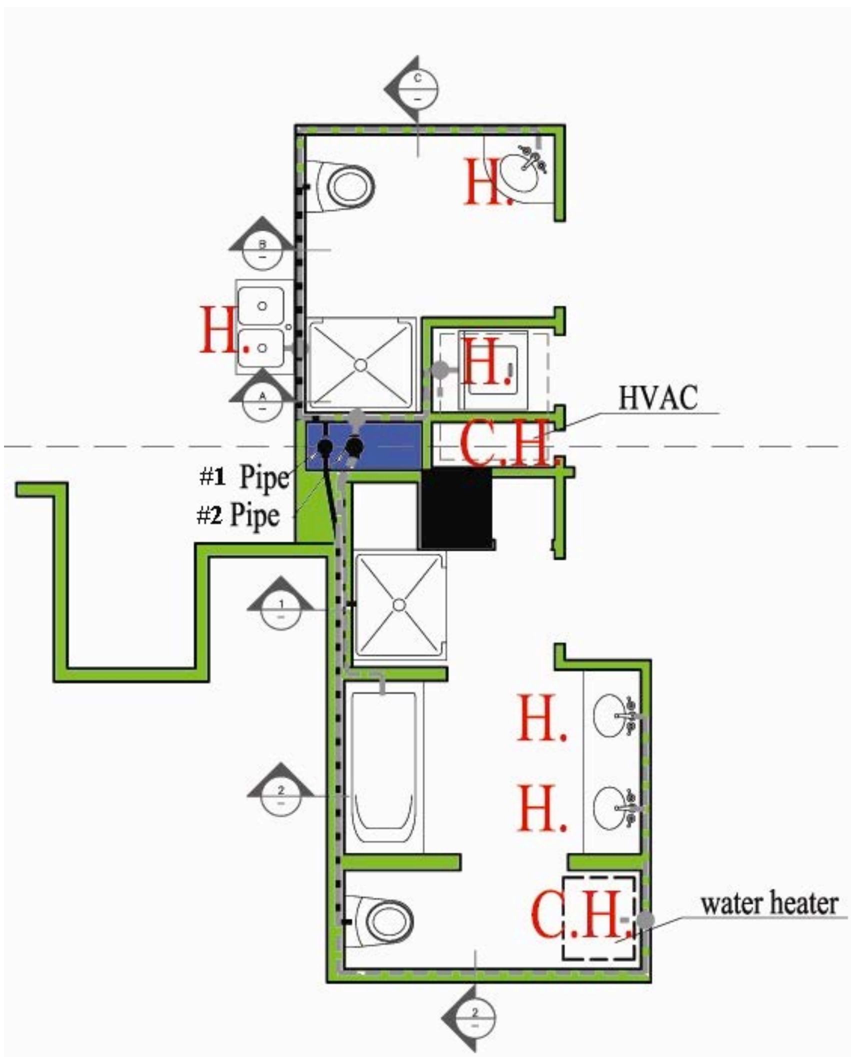


Figure II- 28 This diagram shows the last step in organizing piping “traffic” is to deal with all fixtures that belong to HDZ and CDZ.

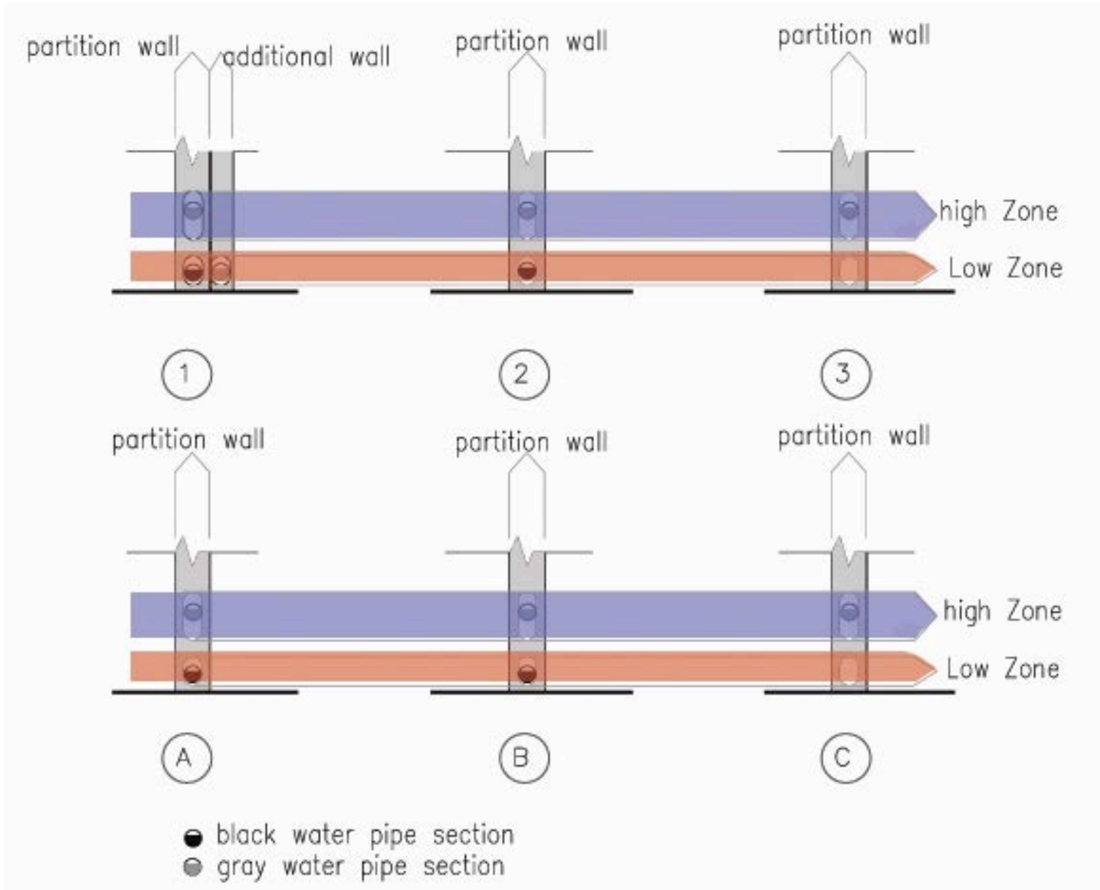


Figure II- 29

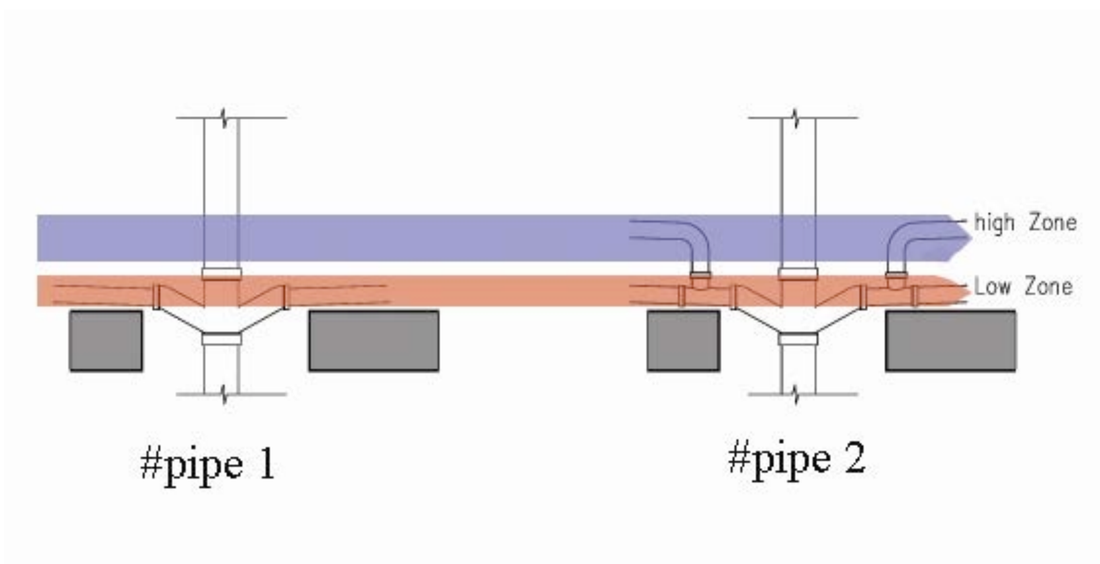


Figure II- 30

II-9 Vertical MEP stack positioning study

In conventional building design processes, plumbing pipes penetrate floors in "sleeves" positioned (or drilled later) depending on each fixture's locations. This is because the plumbing design is done after the layout plan design is fixed and the practice of routing drain lines through adjacent dwelling unit territories (ceilings) has been accepted.

However, in an O.B. design strategy, potential layout plans are studied in advance by means of capacity analysis. The final MEP stack location follows. In this process, all reasonable and potential layout plans that the MEP stack can accommodate are explored. This results in an appropriate MEP stack location. However, it is extremely difficult to position MEP stacks at the beginning of the design process especially for those new in the field. Therefore, it is important to study the design logic involved in MEP stack positioning.

To study the positioning of MEP stacks, a number of conditions must be defined, including the organization of the (proposed – in the case of a new building) floor plate of the building into "zones" adjacent to the façade(s), "zones" with no natural illumination, and so on, oriented parallel to each other in one direction on a building floor plate. In addition, "sectors" can be defined. Sectors are basically sections of the zones of a certain size, making up potential dwelling units (dwelling can consist of one or more "sectors) or partial sectors. A given "zoning" can be divided into a variety of "sectors". Within a given sector, the idea is that a number of functional area distributions (living room, kitchen, etc) can be made. The basic strategy for "zoning" and "sector" analysis and related methods is given in *Variations: The Systematic Design of Supports*. (Habraken, 1981) Once this basic "zoning" is done, more detailed issues such as MEP Stack location can be undertaken.

In this final section of Chapter 2, a more detailed discussion is given on MEP stack location. Of the many constraints or conditions requiring consideration in this decision process, two are mentioned and one is discussed in more detail.

First, it is assumed that no drain piping serving an individual unit alone will penetrate the unit's floor into the lower unit's ceiling. Second, it is assumed that no horizontal pipes within the unit will cross a doorway, as mentioned previously. Third, it is assumed that the location of MEP Stacks is directly related to the structural system and concrete slab reinforcement pattern.

To demonstrate one condition in which the latter consideration is accounted for, a cell of a building using a typical column and beam structural system is selected. This is the structural system found in Case Study 1: the Kales Conversion study. This assumes either a steel beam and column or concrete two-way slab with reinforcing primarily between columns, (Figure II-31). The "space cell" shown can basically represent any building that is being planned using an open building strategy.

In this diagram, five different zones are defined based on their spatial and structural system relations. Black stands for Column Zone. Gray is added to Zones between each column where beans or main reinforcing go, known as "Beam Zones". There are always two light gray orange zones on both sides of a Beam Zone: an "Along Beam Zone". Also, there are usually four orange zones located diagonally around a column, "Around Column Zone". The rest of the space is the "Center Bay Zone" which is shown in yellow.

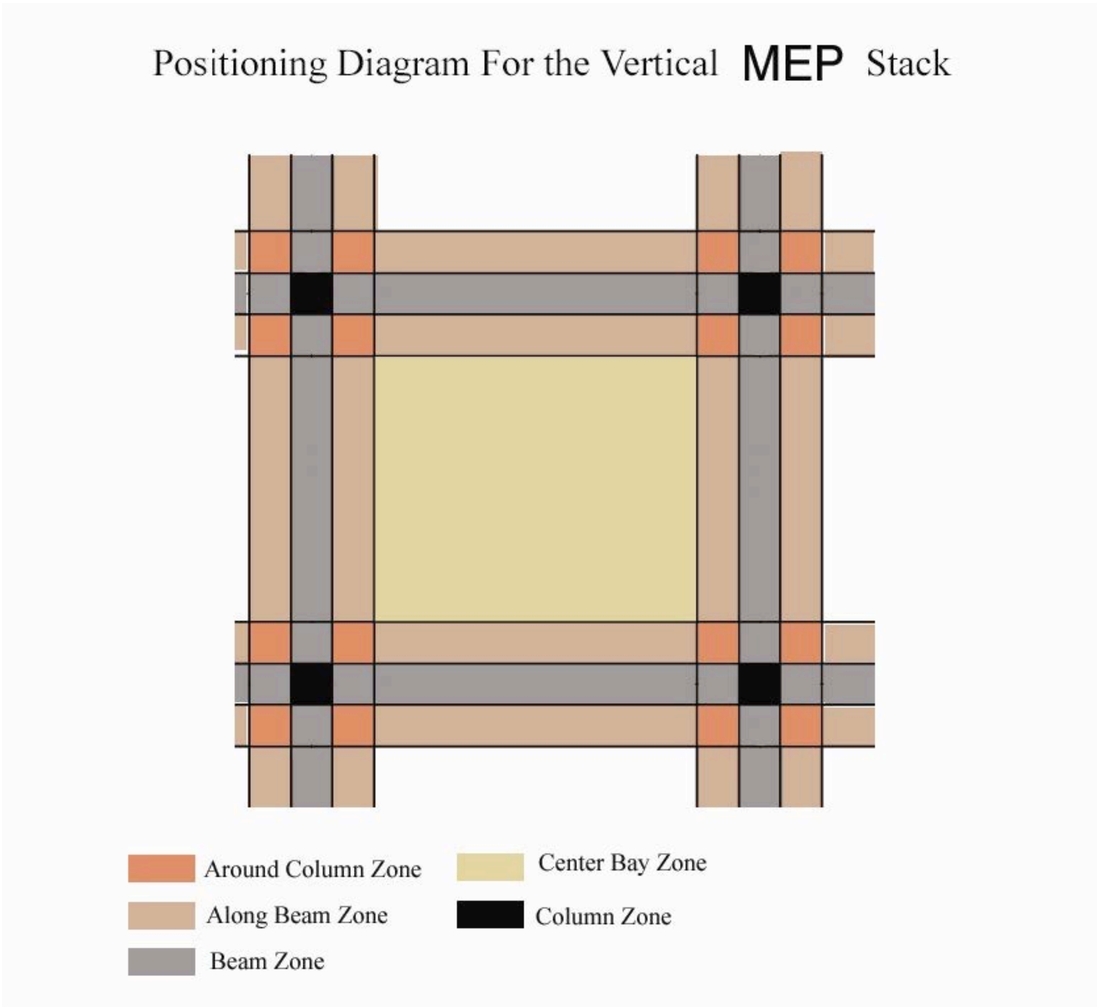


Figure II- 31

When an architect subdivides such a space cell, Figure II-32-a is one normal way to make a smaller space. However, in Figure II-32-b and Figure II-32-c, alternate placements of the same subdivided space are regarded as unusual or even not acceptable, especially in residential projects, because both create awkward spaces that, in most cases, cause spatial inefficiency.

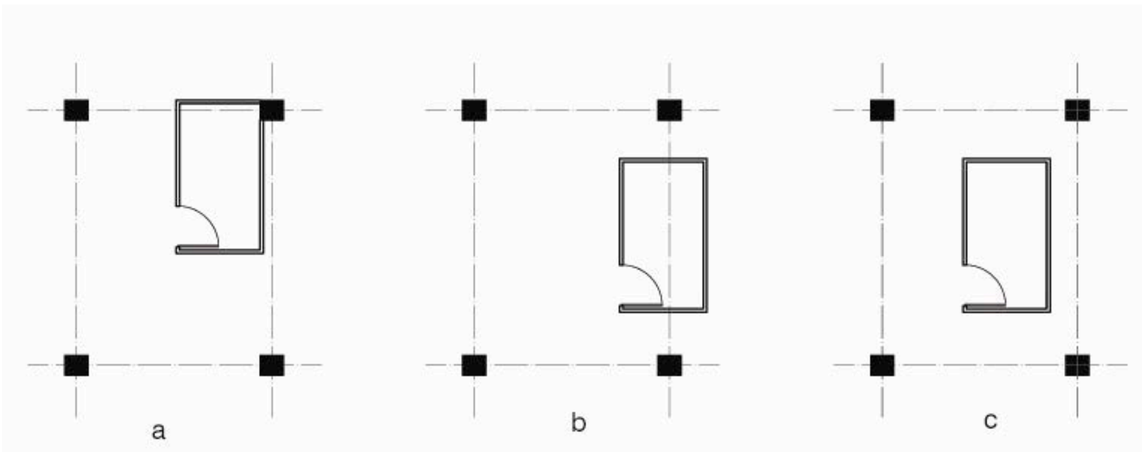


Figure II- 32

In order to explore general constraints for positioning MEP stacks, Figure II-32-a is merged with Figure II-31 into Figure II-33 in which a MEP stack is located in different zones to explore its capacity.

In Figure II-33-a, a MEP stack is located in the Center Bay Zone. In this circumstance, there are two locations that optimize access for bathroom placement: two good access locations and two not acceptable access locations.

In Figure II-33-b, a MEP stack is located in the Alone Beam Zone. In Figure II-33-c, a MEP stack is located in the Around Beam Zone. In both of these two circumstances, there are four "optimum" access locations for bathroom and two "good" access locations.

From the capacity analysis in this example, it is clear that Around Column Zone and Along Beam Zone are appropriate places for locating MEP stacks and the Center Bay Zone is not. In addition, in Figure II-33-a, it does not cause any problem in this specific layout. But after partition walls are removed, and the MEP stack remains, it causes an awkward situation in which the space can not be designed as a living room because the stack is standing right in the middle of the space cell. This greatly reduces the capacity of the space to accommodate a range of functional layouts. Similarly, in Figure II-33-b, it eliminates the possibility of combining two adjacent construction bays as one big open space such as a living room. In other words, MEP stacks located in the Center Bay Zone or the Along Beam Zone eliminates important layout variations. Around Column Zones are always the priority locations for positioning MEP stacks. This principle appears to be generally applicable. However, in some specific circumstances, Along Beam Zones are also suitable for placing MEP stacks. Only in a few circumstances can Center Bay Zones be considered to place MEP stacks.

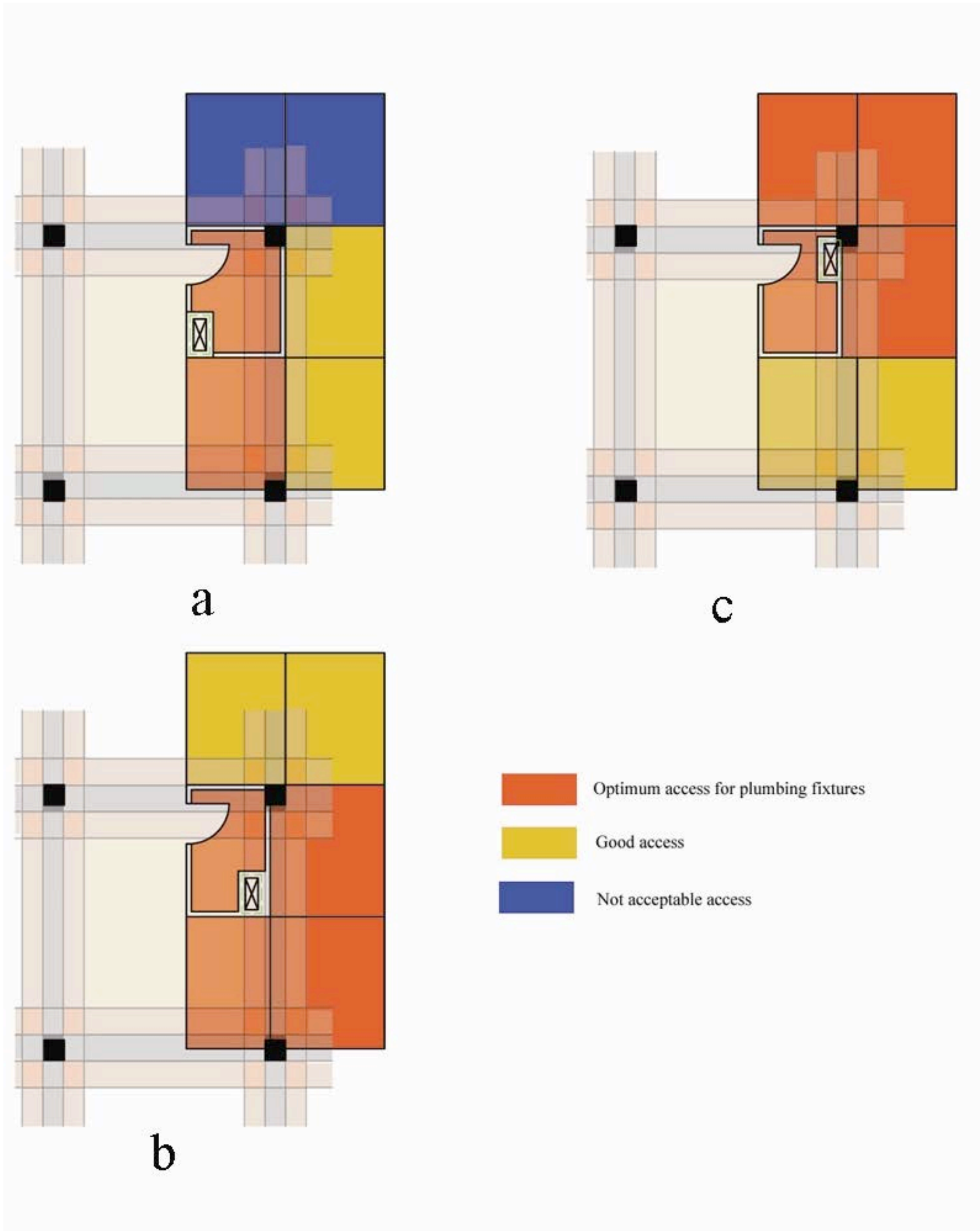

a
c
b
Optimum access for plumbing fixtures
Good access
Not acceptable access

Figure II- 33

CHAPTER III

OB Conversion: A design process using capacity analysis

Chapter introduction

The following is a "step by step" demonstration of how to design a floor plate in a high-rise building being converted to residential uses, when capacity analysis is needed. In retrospect, the design process initially involved a great deal of trial and error; it was definitely a "back and forth" process. The following is an attempt to "revisit" the design thinking and therefore to clarify how capacity analysis is done, for others who may get into the field and who may be asked to provide decision and design flexibility. However, residential design work is complex, requiring a certain level of professional training and knowledge beyond what is explained here. Therefore, this chapter does not try to explain every step. Many principles of common sense to professionals are assumed as conventional knowledge, for example the arrangement of sanitary fixtures, normal room sizes and arrangements, and so on. Many standards exist in handbooks and references, such as the layout of different size rooms. (See Appendix II) (Macsai, 1982; Liu, 2000)

III-1 Step 1- Initial floor plan study.

In this demonstration, the kales project which an high-rise historical office building being converted to residential occupancy. Before the O.B. design, an architect firm (BVH Architecture INC. Detroit. Michigan) had already developed a series of floor plate layouts and unit designs as the drawings below show. So there were floor plans to examine. But, because an OB design process does not seek fixed floor plans but rather possibilities, it is probably a good idea in such a case to avoid studying the original plan drawings too closely except to understand the basic unit sizes and types (Figure III-1). However, it is recommended that conventional plans be reviewed after some variations are explored. They can provide "base-line" rationale of "why I didn't design in this way? Are these plans better for the market...?"

All interior partitions and fixtures should be erased from the original plan drawings, leaving the skeleton of the building (columns, floors, exterior walls) and the public circulation (stairs, elevators, public corridors, and public service risers and rooms). (Figure III-2)

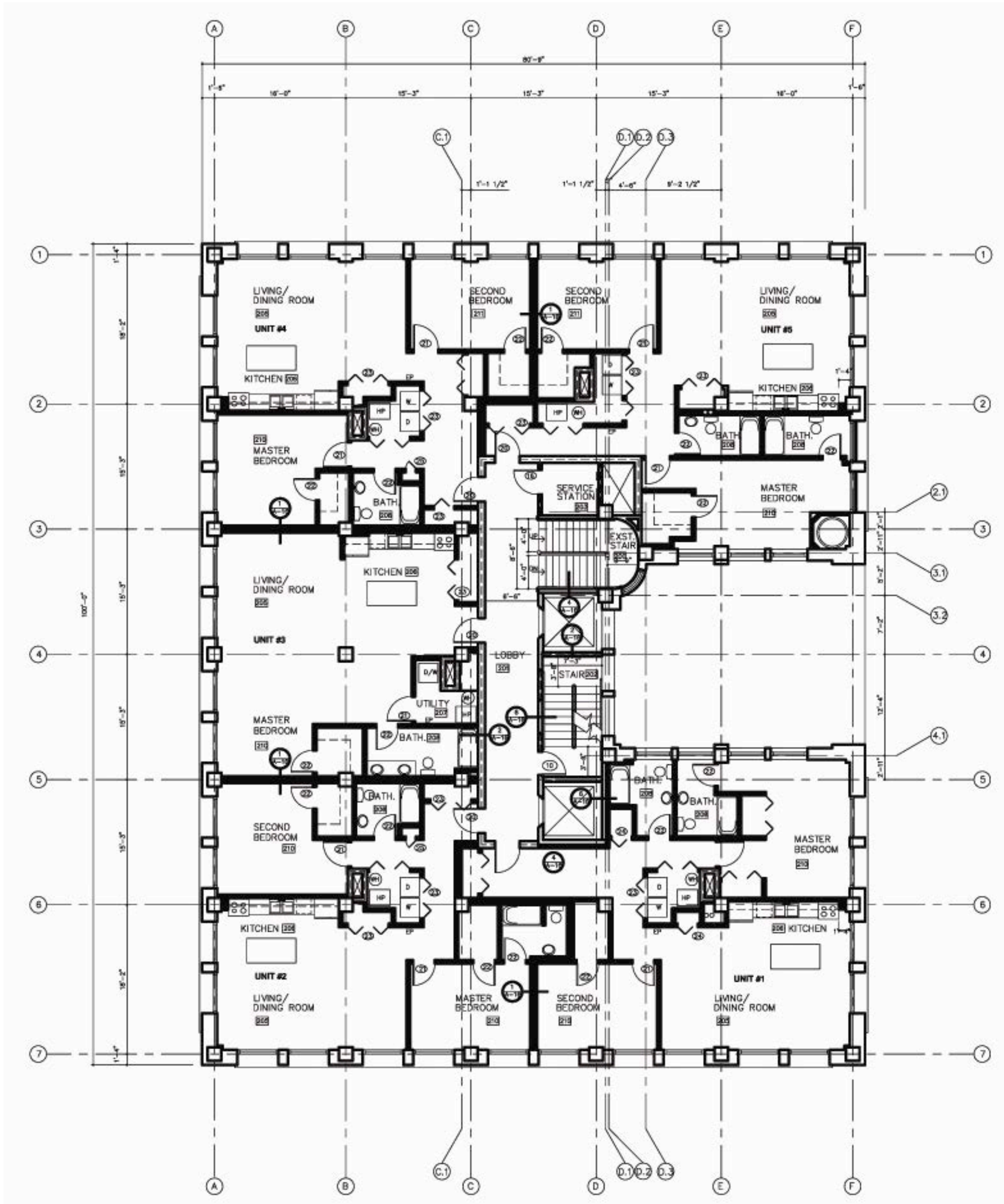


Figure III- 1. The first attempt to fix the floor plans by the project architect

(SOURCE: BVH Architecture, INC. Detroit. Michigan)

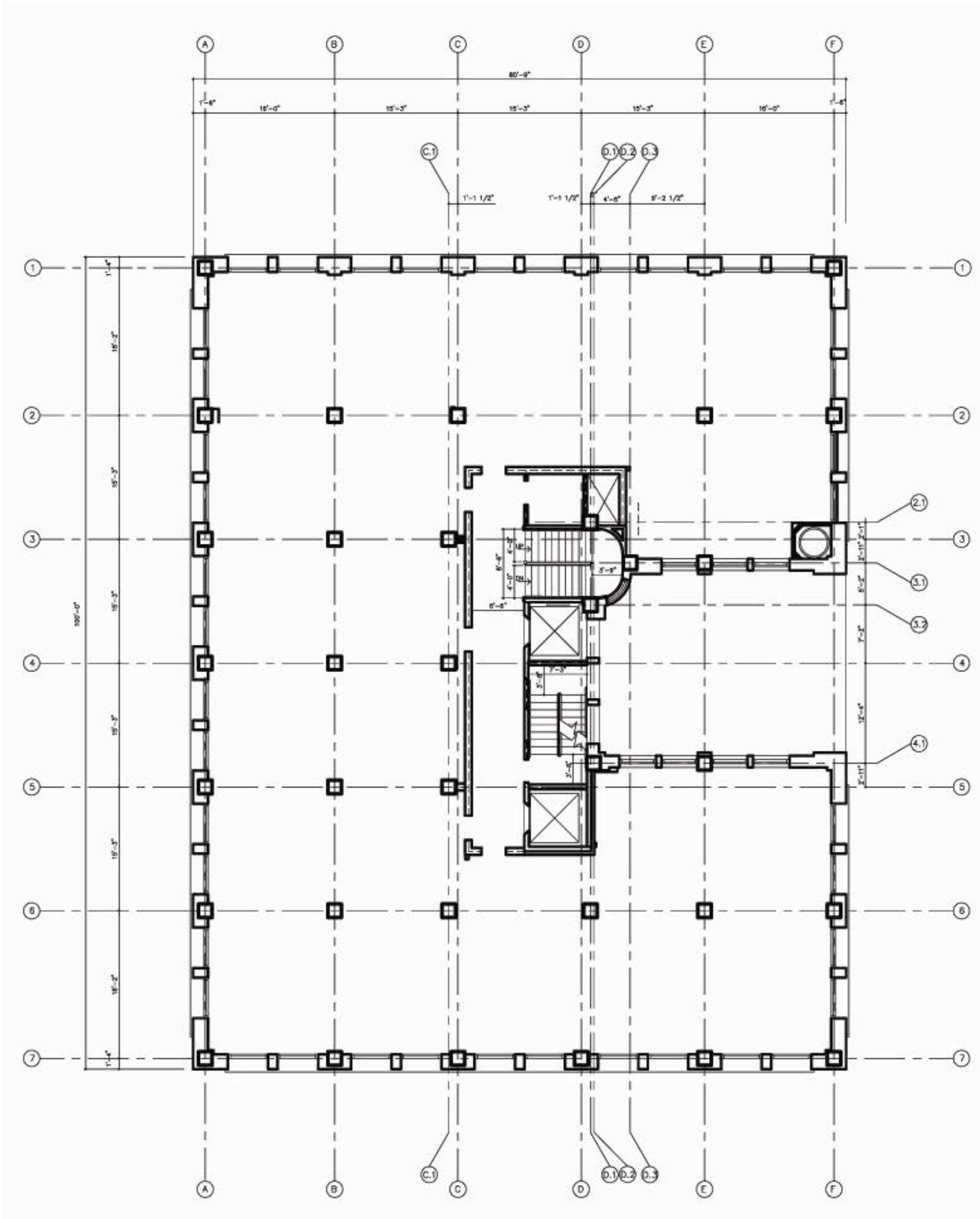


Figure III-2. The BASE BUILDING after partition walls and fixtures are removed, the “Shell” of the building remains and is ready for capacity analysis studies and MEP stack location decisions.

III-2 Step 2- Placing demising walls to create basic unit sizes and margins.

Using demising walls, (walls separating different tenant spaces or legal "territories") the floor plan can be divided into a number of average size units. In this example, the average unit size is around 800-1000 sq.ft. Therefore, 5 basic units are defined (Figure III-3). Margins can be placed between each unit based on the column arrangement and the openings in the exterior wall. Margin size is ideally around 20% of the basic unit size. (Figure III-4)

Other demising wall distributions and margins in the same base building are possible based on different assumptions about unit sizes. It should be noted also that in the proposed unit distribution that follows, other variations of unit sizes are possible, such as very large units on the same floor as smaller units.

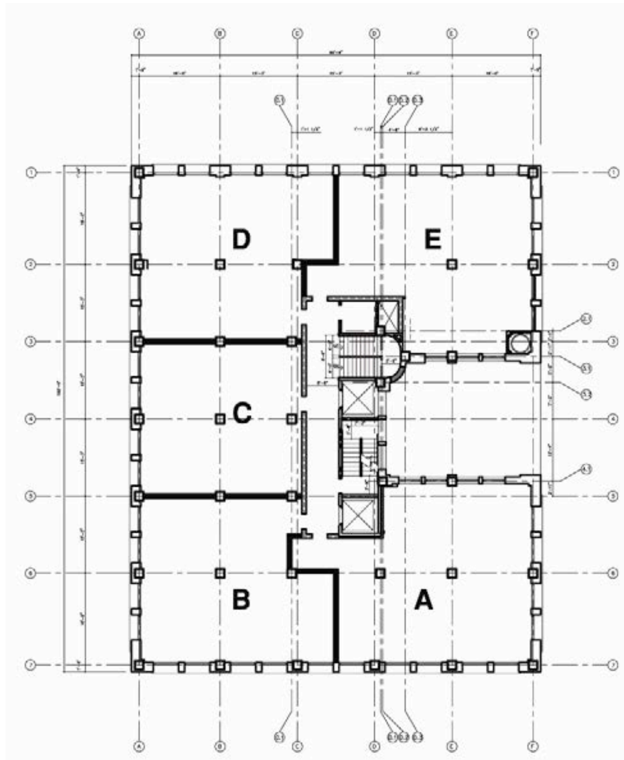


Figure III- 3. Five basic units are defined by using demising walls**.**

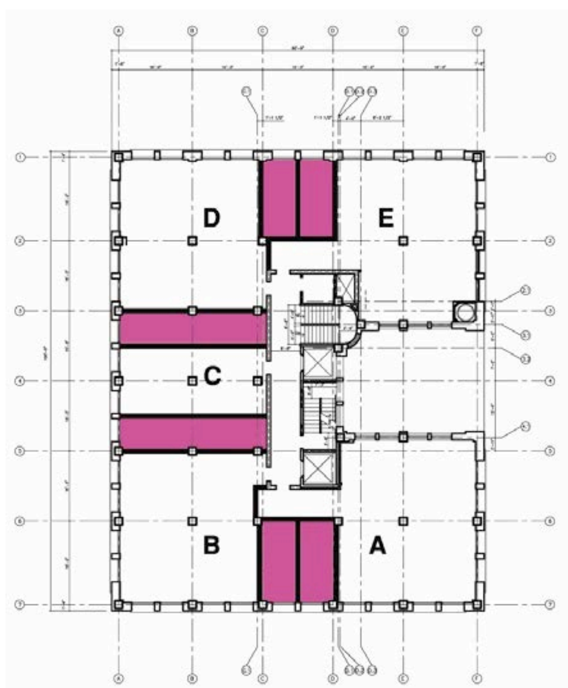


Figure III- 4. Margins are created by shifting demising walls enabling a variety of unit sizes on a given floor.

III-3 Step3- Developing an individual dwelling unit.

Once a tentative distribution of unit "territories" is made (Step 2 above), it is possible to explore the capacity of such a territorial unit in terms of what floor plans it can accommodate.

In this demonstration, Unit A is selected. Three unit sizes are possible, by placing the demising wall in three locations that accommodate the column arrangement and exterior wall openings, and that share the same entry door to the unit (fixed as part of the base building decision). It is always highly recommended to choose the medium size unit to develop variations at the beginning. This is because functionally it is somewhat close to both small and large sizes. After developing the medium size unit variations, (most of these variations layout ideas are similar), they can be simply modified by enlarging or eliminating rooms.

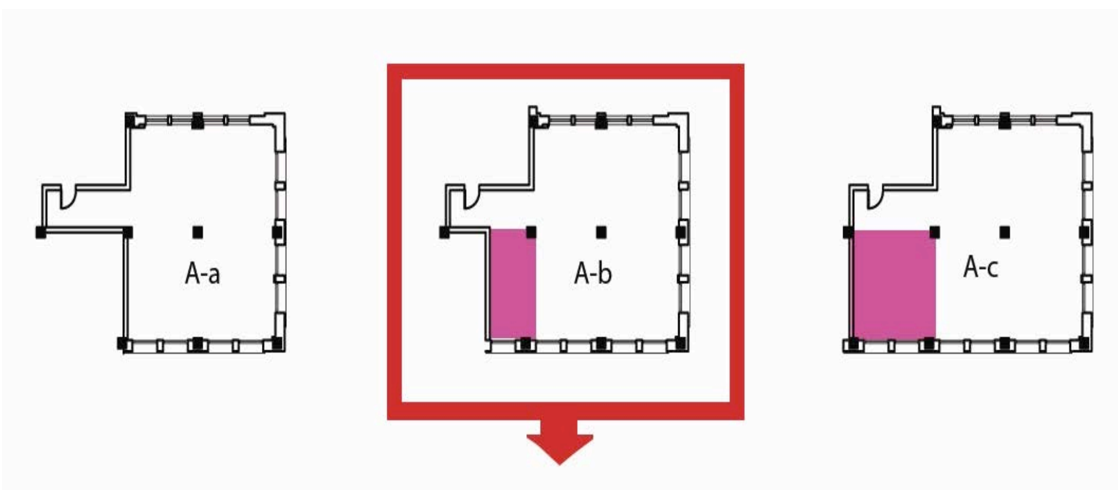


Figure III- 5 Among three sizes, the medium size unit (A-b) is chosen for further study and development.

III-4 Step 4 – Placing rooms inside the unit.

a) Rooms & unit shape study.

Before starting this step, it is necessary to study the relations between different functional areas (rooms) and the unit shape and size. In a typical residential unit, there are basically 7 different kinds of rooms: living rooms, bedrooms, kitchen, bathroom(s), dining room, utility room and storage rooms or closets. Among these rooms, some (by code or convention) need to be next to an exterior wall to get natural light, ventilation or views from windows; these are living room and bedroom (in some jurisdictions for some buildings such as conversions, bedrooms need not be adjacent to the façade in cases in which high ceilings allow light and ventilation in bedrooms with partial-height walls). Some rooms are preferred to have exterior openings, such as the dining room and kitchen. Bathrooms and kitchen do not necessarily have exterior openings; utility room, laundry room and storage room require no exterior openings. (See Table III-1)

Required to have exterior opening(s)	**Prefer to have exterior opening(s)**	**Not necessary to have exterior opening(s)**	**Require no exterior opening(s)**
Living Room Bed Room	Dining Room Kitchen	BathRoom	Laundry Room Utility Room

Table III- 1

b) Study the capacity of the space

In order to understand the unit space and locate MEP stacks in suitable places serving a range of floor plans, the unit space is studied and analyzed in different ways. In Figure III-6, the functional division of the space is analyzed. Based on the shape of the unit, and also the depth and width, two zones are defined. One is the service zone and the other is a living zone. Living rooms and bedrooms are placed in the living zone in which they can have exterior openings. Utility room, laundry room and storage rooms are placed in the service zone. Kitchen and dining room are placed between zones because they can be placed in both zones depending on the design circumstance.

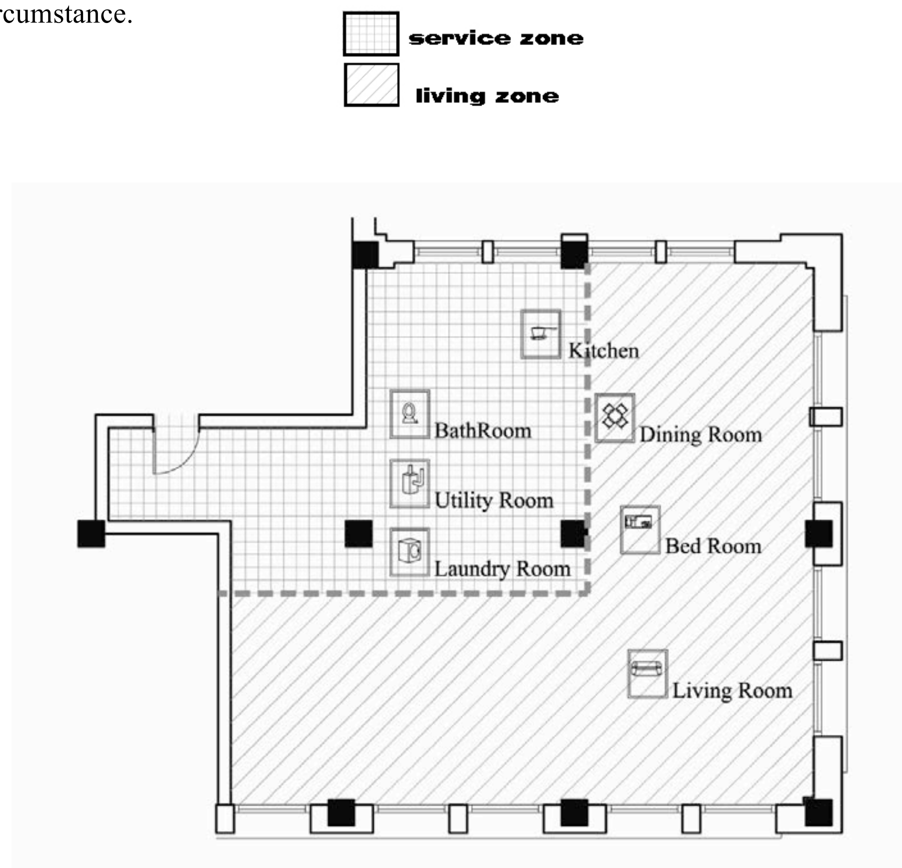


Figure III-6. Different rooms are placed in two zones inside a unit.

c) Study the relation between rooms and MEP stack.

The second move is to categorize rooms by their relations with MEP stacks, yet to be positioned. Basically, there are three kinds of rooms. 1) Rooms that need to be directly next to an MEP stack. These are “public” bathrooms and master bathroom. 2) Rooms that need to have at least one continuous wall without door openings connecting to a MEP stack; these are utility room, laundry room and kitchen. The distance from these rooms to the MEP stack can be further (up to 50’) based on constraints introduced in Chapter II3) Rooms that need no wall and connections with MEP stacks, these are living rooms, bedrooms, dining room and storage room.(See table III-2)

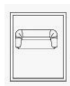
Rooms needing to be directly adjacent to an MEP stack	**Rooms needing to have a continuous wall connected to an MEP stack without door openings**	**Rooms with no need to connect to an MEP stack**
 BathRoom  Master Bed Room	 Laundry Room  Utility Room  Kitchen	 Living Room  Bed Room  Storage

Table III-2

d) Study the circulation flow inside the unit

The circulation of the layout plan also effects the locations of MEP stacks. Therefore, it needs to be studied. Normally, in high-rise residential buildings, public spaces that are part of the Base Building - such as fire stairs, elevators, and public corridors - are mostly located in the core of the building. The result is that the entrance of the unit is always located on the side of the dwelling unit's service zone. Typically, there is always a circulation flow across the service zone distributing to each room. (See Figure III-7)

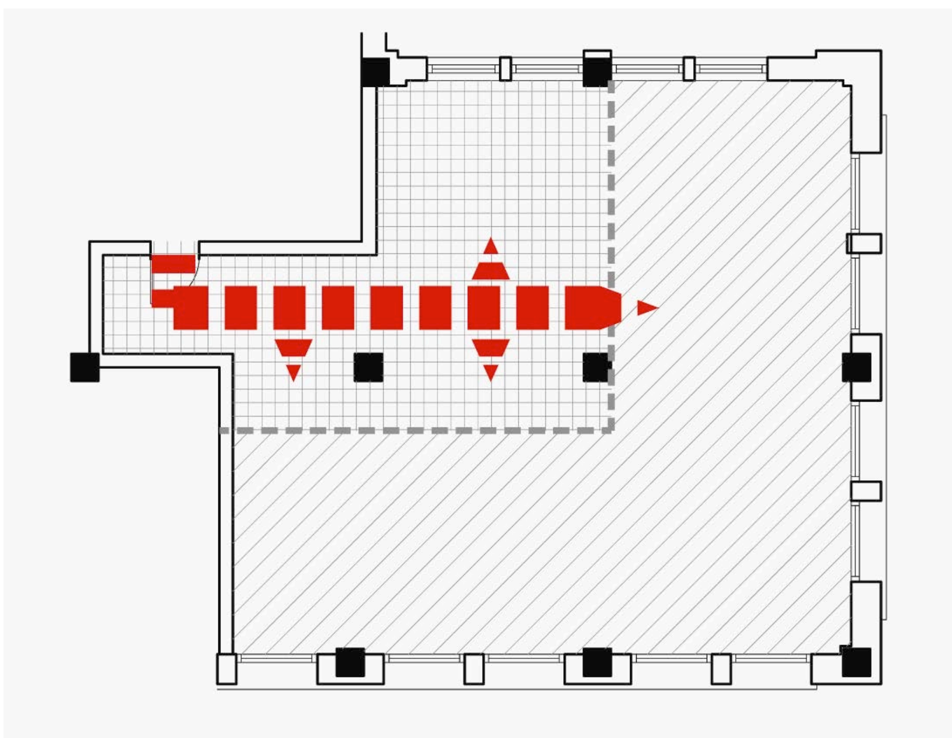


Figure III-7. A circulation flow passes through the service zone to each room inside the unit.

III-5 Locate the MEP stacks

III-5-a Deciding on the number of MEP stacks in a unit

Theoretically, one MEP stack can serve one dwelling unit and a variety of layouts in it. However, there are two constraints in that case. 1) There are not many variations to be offered when there is only one MEP stack in one unit. 2) As shown in Figure 6, there is always a corridor crossing the service zone and dividing it into two parts. This crossing “cuts” the service zone into two parts in which one MEP stack can not connect to the other side of the corridor. Therefore, there should be two MEP stacks, located on both sides of the corridor. (Figure III-8) Hence, in general, two MEP stacks in a medium size unit have the most variation capacity and efficiency. Subsequent drawings demonstrate these points more fully.

III-5-b Define suitable zone for MEP stacks

In this step, comprehensive knowledge is required as well as the sense of different room sizes during decision-making. During this part of the design process, the layouts of different size rooms have been studied (see Appendix II) in order to have a good sense in placing MEP stacks in suitable locations accommodating more layout variations. Technical rules and design constraints developed in Chapter II (see Page 43-48) proved to be useful in making MEP stack location decisions, in most circumstances.

After studying various circumstances in terms of shape of the unit, circulation paths and so on, two Zones suitable for placing MEP stacks are defined. (See Figure III-8)

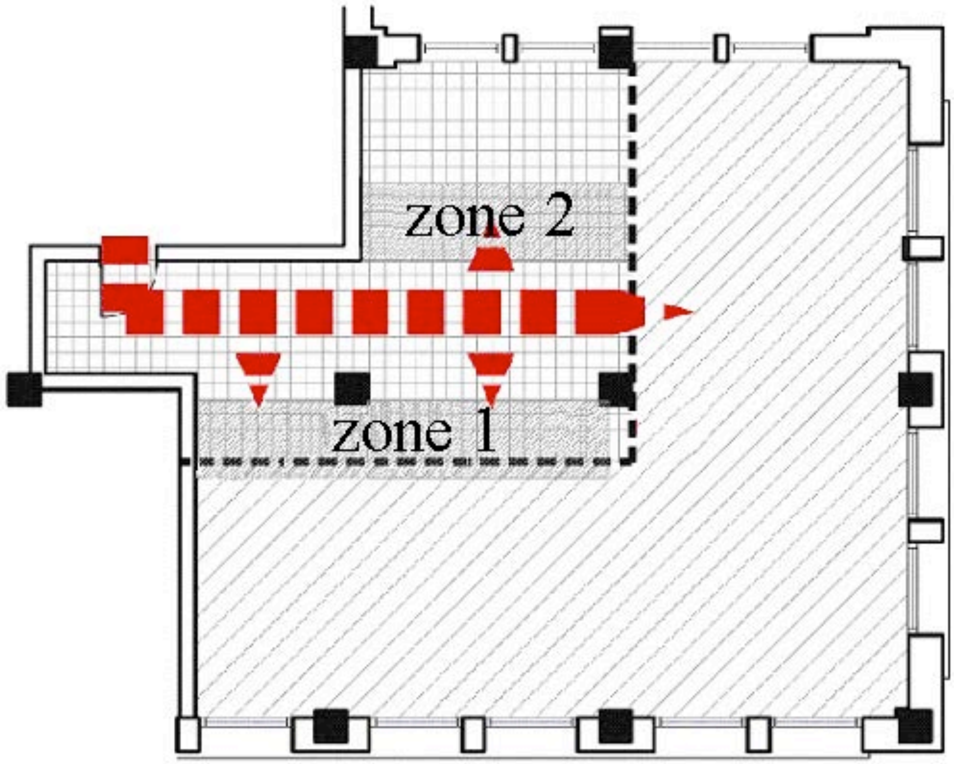


Figure III- 8. Two zones that are suitable for placing MEP stacks are defined after the unit study.

However, only defining suitable MEP zones is not enough to find the exact spots to locate MEP stacks. After the Positioning Zone Diagram is overlaid on the appropriate Construction Bay Diagram, 11 spots are defined.. Those located at the intersections of the two diagrams can be defined as the more optimum MEP positions. In diagram III-9, A, B, C, F, are located at the intersections of two overlapping diagrams. L, H, J, K are therefore not so suitable for placing MEP stacks. ("Trial and error processes" are already applied in those locations, and demonstrated that they are not suitable for placing MEP stacks.)

Thus, A, B and C are defined as suitable locations for the MEP “below” the circulation flow. Two (E.F.) are suitable positions for the MEP stack on the other side of the circulation flow (Figure III-9). These optional positions are suggested also in light of the earlier discussion of MEP stacks in relation to building structure

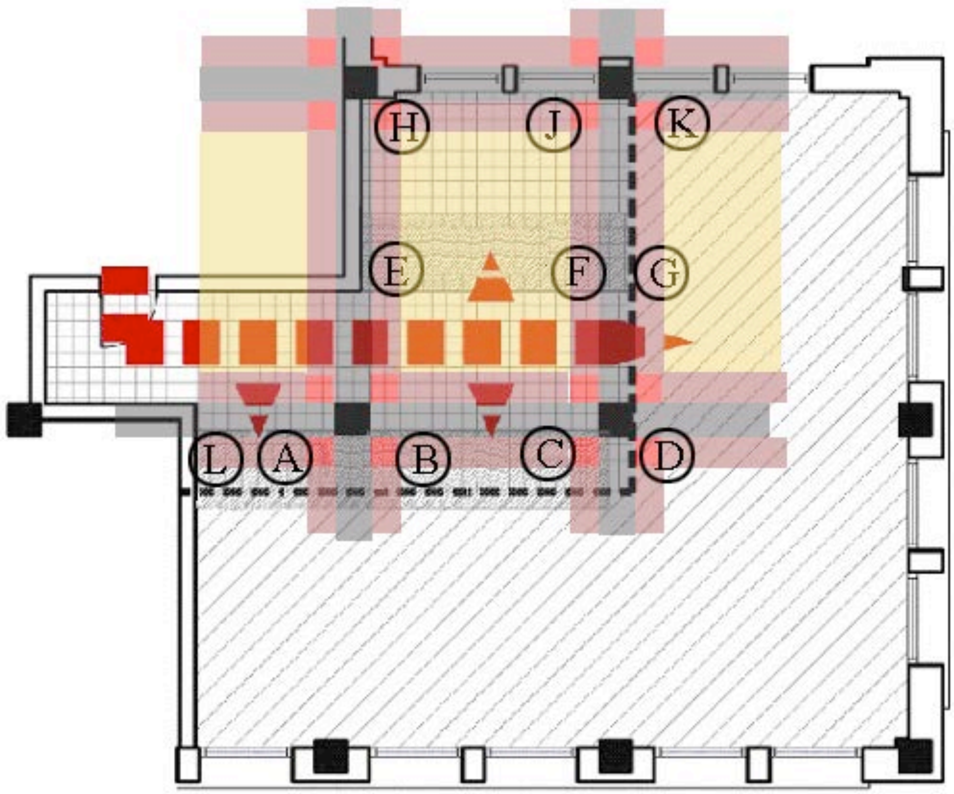


Figure III-9. Two diagrams are overlapped to define optimum locations for placing MEP stacks.

III-5-c Eliminating unsuitable MEP locations.

In this step, optimal MEP locations can be selected by eliminating others based on the kind of "dialogue" as follows. In Figure III-9, "**A**" can be eliminated because it narrows the space of potential circulation flow; it creates a "not too big, not too small" space in which a bathroom and a door entrance can not fit; and it is too large only for an entrance door way. When locating MEP stacks, it is recommended to "think" or foresee (if not explicitly sketch) potential rooms around the MEP stack. Theoretically, an MEP stack should be surrounded by rooms that need to connect to it. Therefore, potential living room, dining room, storage rooms are better when they avoid MEP stacks.

"**C**" can also be eliminated because they are located on the "right" side of the service zone, making them inaccessible to possible "plumbing dependent" spaces to the left side of the service zone in the diagram. Nevertheless, there are two potential circulation flows between the left side and "**C**". In conclusion, they are not suitable locations for placing a MEP stack.

Similar to the situation of "**C**" and "**D**", "**F**" can be eliminated.

Therefore, "B" and "E" are defined as suitable MEP locations to develop unit layout variations in this instance. Moreover, the orientation or "direction" of an MEP stack should be determined during the process of developing more detailed variations. (See Figure III-10)

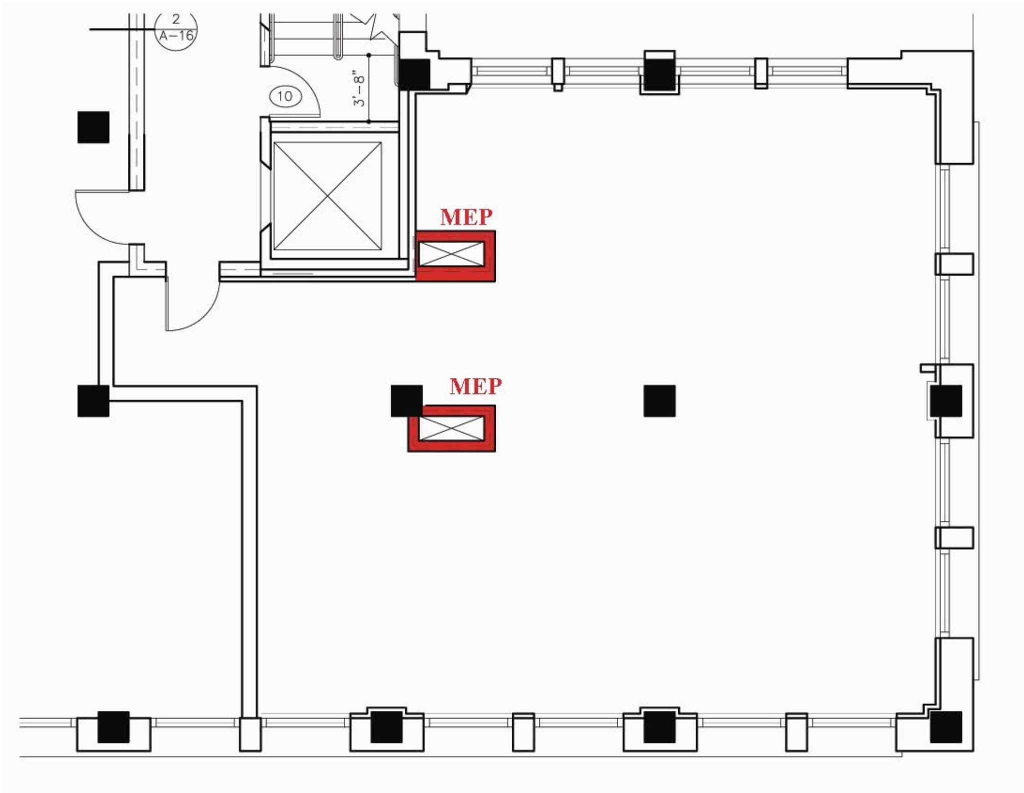


Figure III- 10. After studying the location of MEP stacks, the positions are fixed offering unit layout variations. In this figure, two MEP positions are placed accordingly.

CHAPTER IV

CASE STUDIES

IV-5 Aim of the case studies and method of evaluation

After developing a series of design constraints in plumbing that can be used as design methods or technical rules for capacity analysis in residential floor plan layout, the following case studies are used to demonstrate these constraints. As a result of these two cases, it appears that these constraints are general and systematic enough for application in other high-rise residential floor plan capacity analysis. They are thus proposed as useful tools for practitioners or students who want to design open building projects under similar circumstances.

These case studies have similarities and differences that make them useful. Both are high-rise buildings with all the code and construction constraints associated with that construction type. Both are "existing" in the sense that the capacity analysis and constraints were not focused on entirely new building design, but accepted an existing base building architecture.. Differences exist in the exact kind of structural system, and in the target market for the buildings, resulting in different levels of complexity (e.g. number of fixtures in a unit) and dwelling unit sizes.

The first study is the Kales building, a vacant multi-story historical office currently being converted to a residential building. A unit was selected as a full demonstration to explain the step by step O.B. design process by applying constraints which are developed in the former chapter. The study is more general, and the design methods are considered to be applicable to other O.B. designs and as guidelines for beginners. Therefore, it is the main case study.

The second case study is a new multi-story mix-use building (now under construction) the lower floors of which are hotel rooms and the upper floors are luxury residential condominium units. The condominium floors are used for the case study and at the time of this writing were still being designed even as the foundations were being poured. It shares many fundamental design principles with the former case study. However, it is a newly built post-tensioned structure, with a higher standard of luxury in term of the sizes of units and even the quantity of bathrooms which present more constraints. In this case study, more design constraints are testified to be general enough for principles of O.B. capacity analysis.

IV-6 Case study I – the Kales building conversion study.

Project Location: 76 West Adams, Detroit, Michigan

Owner: Mansur Real Estate Services Company

Project Introduction: See chapter I (page 6-10)

Task: An 18-story vacant historical office being converted to residential occupancy with unit decision deferring for developer, various unit variation for future tenants and reduce unit territory entanglements.

Methodology: Based on O.B. concept, accepting the building conditions (given constraints) and using the methods and technical rules developed in the thesis (designed constraints) to design unit variations to approach the task.

Figure IV- 1. These are Kales Building exterior photographs.

(Source: Stephen Kendall)

Design result:

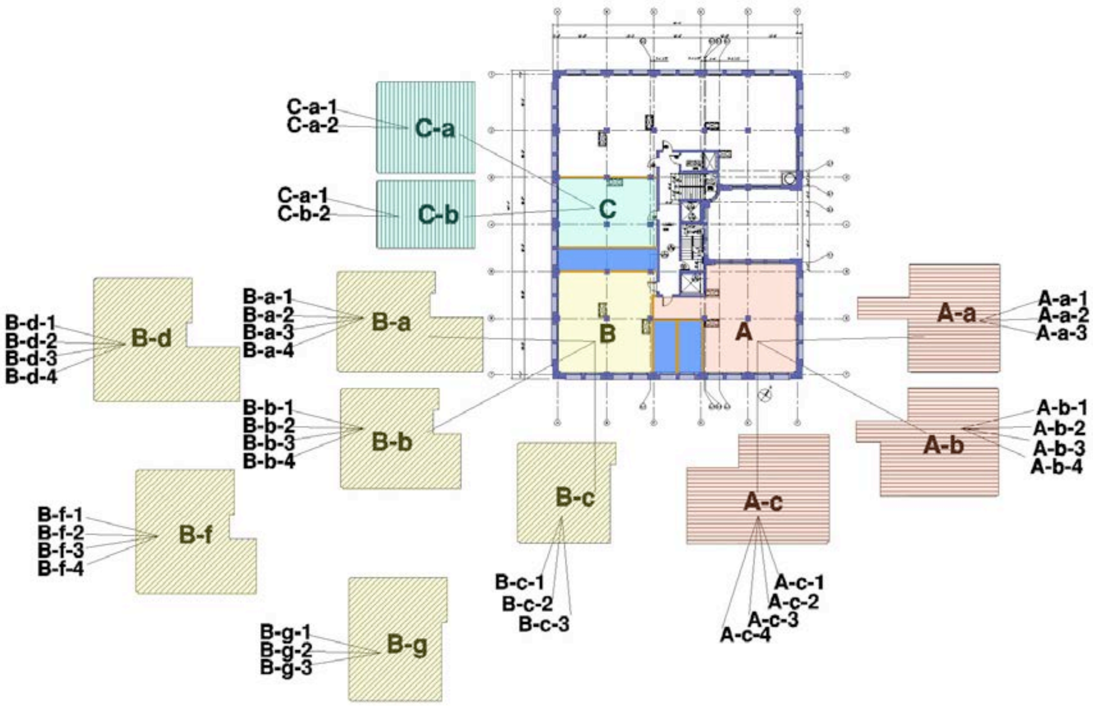


Figure IV- 2. A "tree" diagram shows possible layout variations that a base building can provide.

In Figure IV-2, MEP stacks are pre-located as a part of the Base Building. Using demising wall can create margins between units and result different units in various sizes (Size Variations), for instance, *A-a, A-b,…B-a,….* Each Size Variation can be developed various layout plans (Unit Layout Variations), for instance, *A-a-1, A-a-2,....*Therefore, there are proximally sixty variations can be developed, and thirty variations have been developed from A unit to C unit. (See Appendix III) The methods and technical rules have been used and proved to be available for the "operation" of capacity analysis.

In order to fully demonstrate the methods and technical rules can be available for operating capacity analysis in the units that developed in these case study, four variations are selected among these thirty variations to present more technical details. In these diagrams, Blue color stand for the Base Building; red spots are where MEP stacks locate (actually, MEP stacks belong to Base building which are in blue. However, they are in red color in order to emphasize and easy to be seen.); Walls in green are infill walls; Magenta walls are demising walls which separate unit territories; Color cyan area indicates areas do not need MEP stacks; Orange areas indicate they have pipes going to the MEP stacks; and blue walls belong to Base Building.

a) Variation example: A-b-1

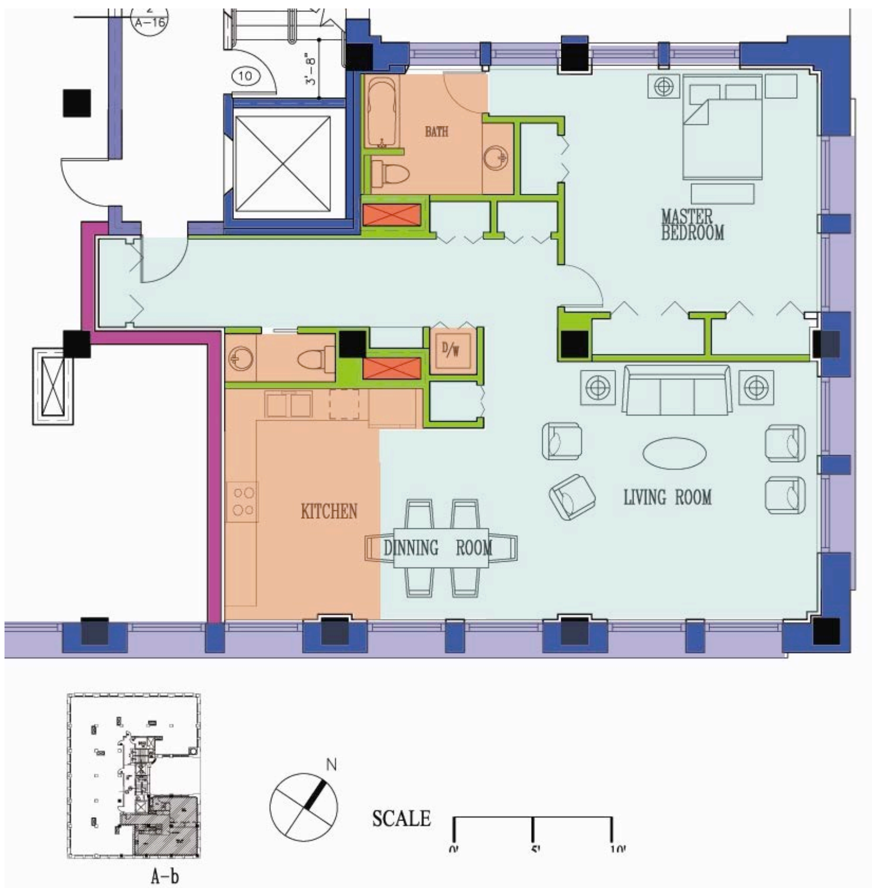


Figure IV- 3. This is variation A-b-1 layout floor plan.

The layout floor in Figure III-3 shows no differences to other conventional designs. However, the significant difference is that all drainage pipes have no entanglements with the building floors (or the Base Building). To approach these criteria, sanitary fixtures must follow the rules that developed in this thesis and use the technical methods to install. The flowing diagrams show more details in piping system to demonstrate how to make them implementary.

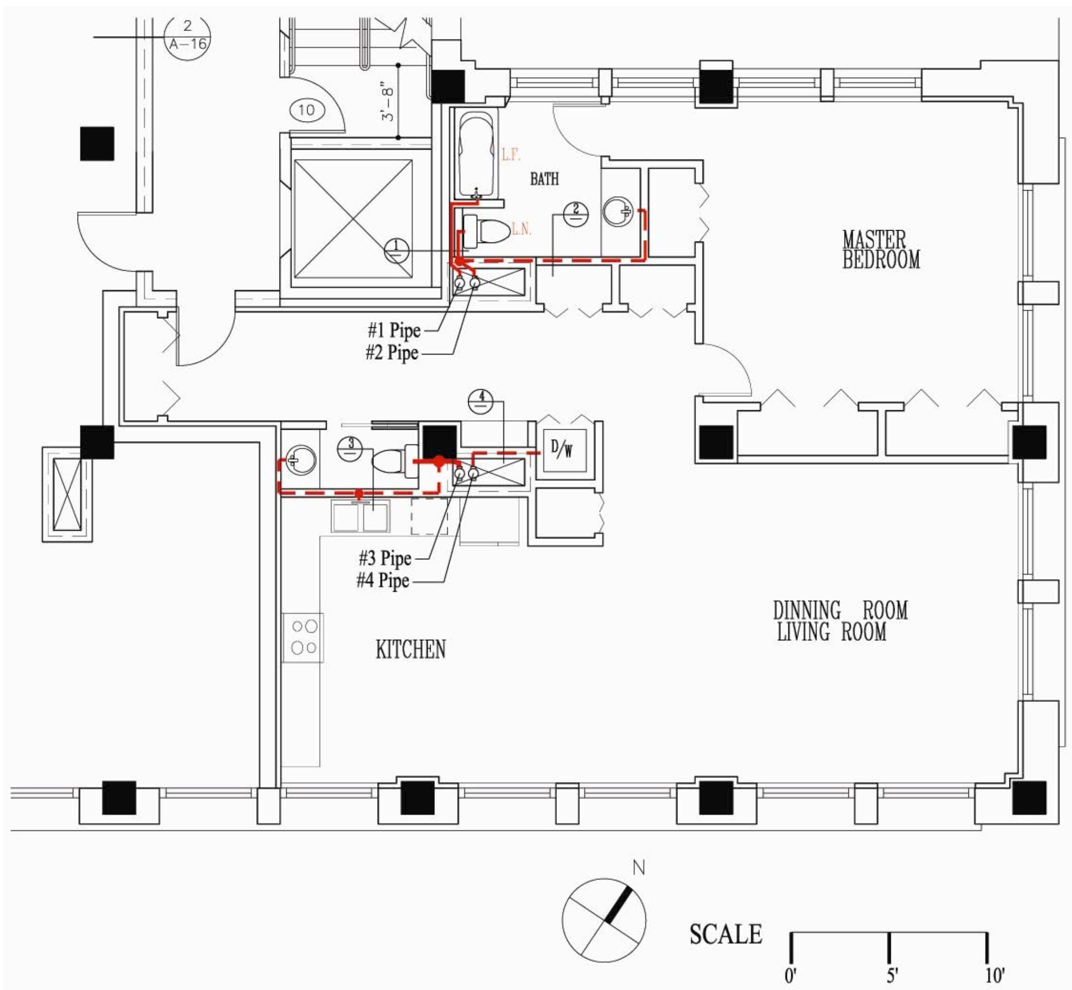


Figure IV- 4 .Piping diagram

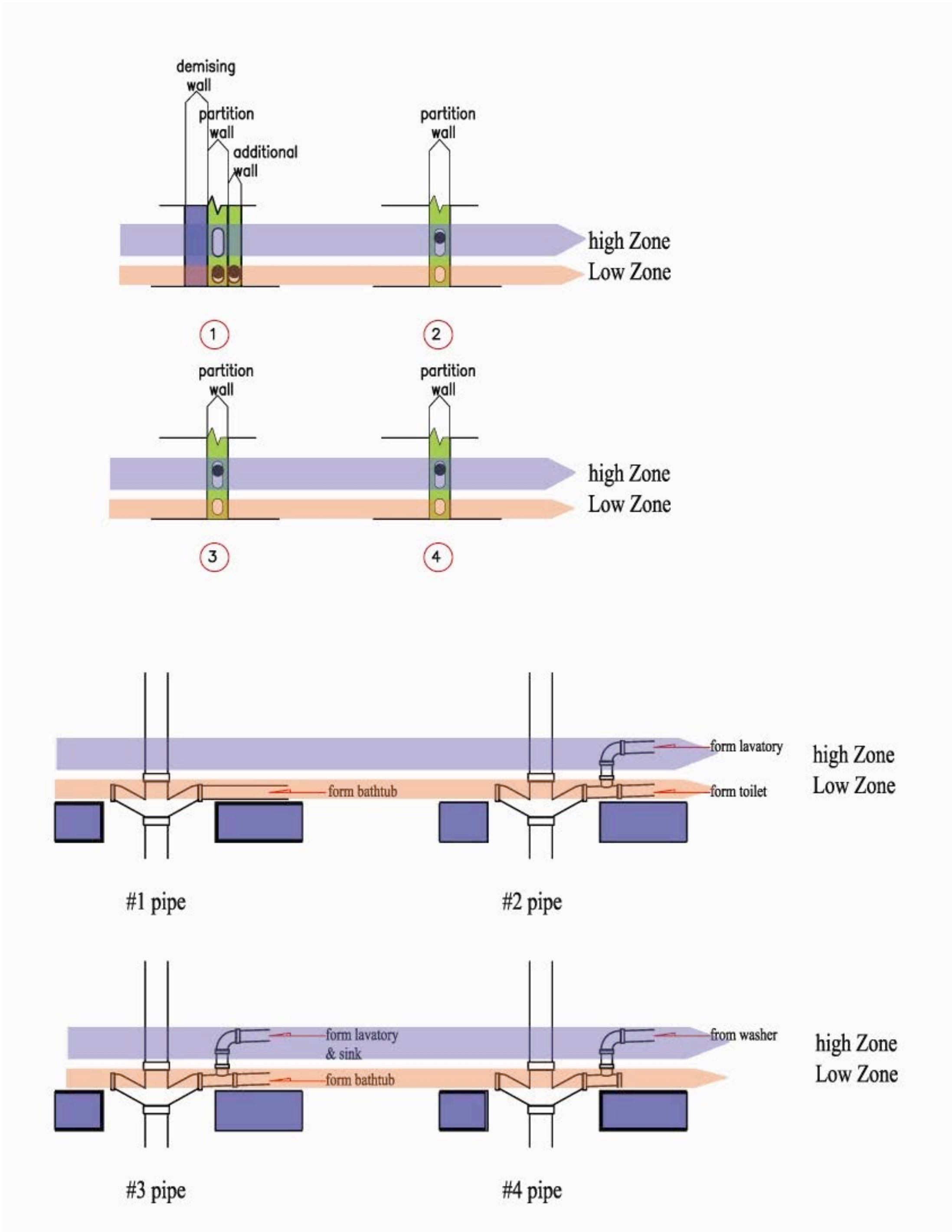


Figure IV- 5 Wall sections and MEP stack elevations.

b) Variations example A-b-2

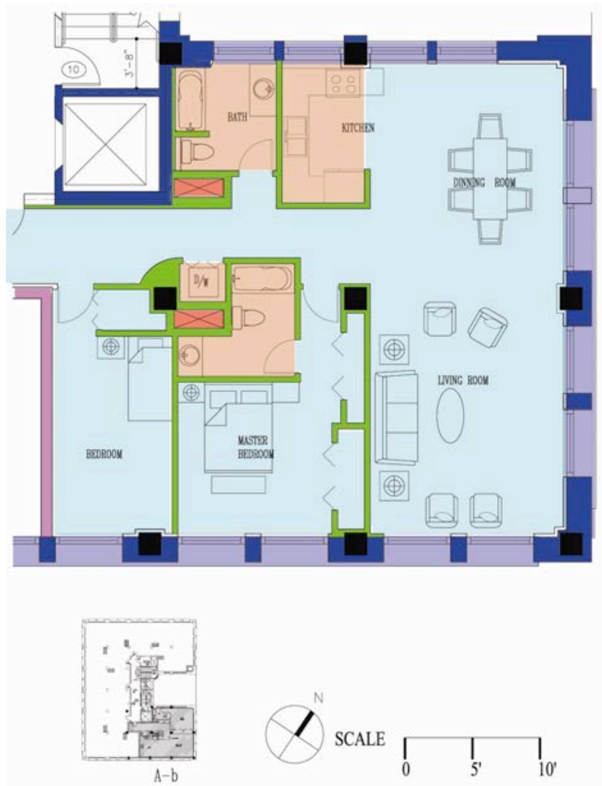


Figure IV- 6 This is another layout variation for A-b size unit.

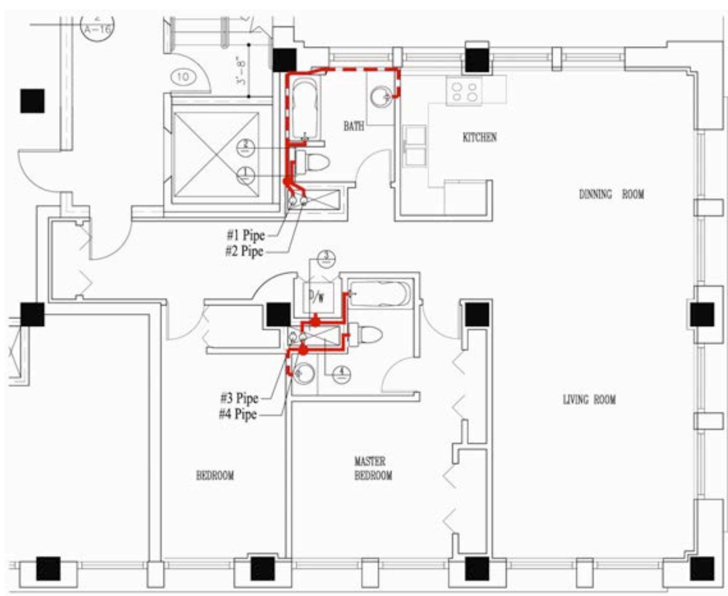


Figure IV- 7 Piping diagram for one layout of unit A-b.

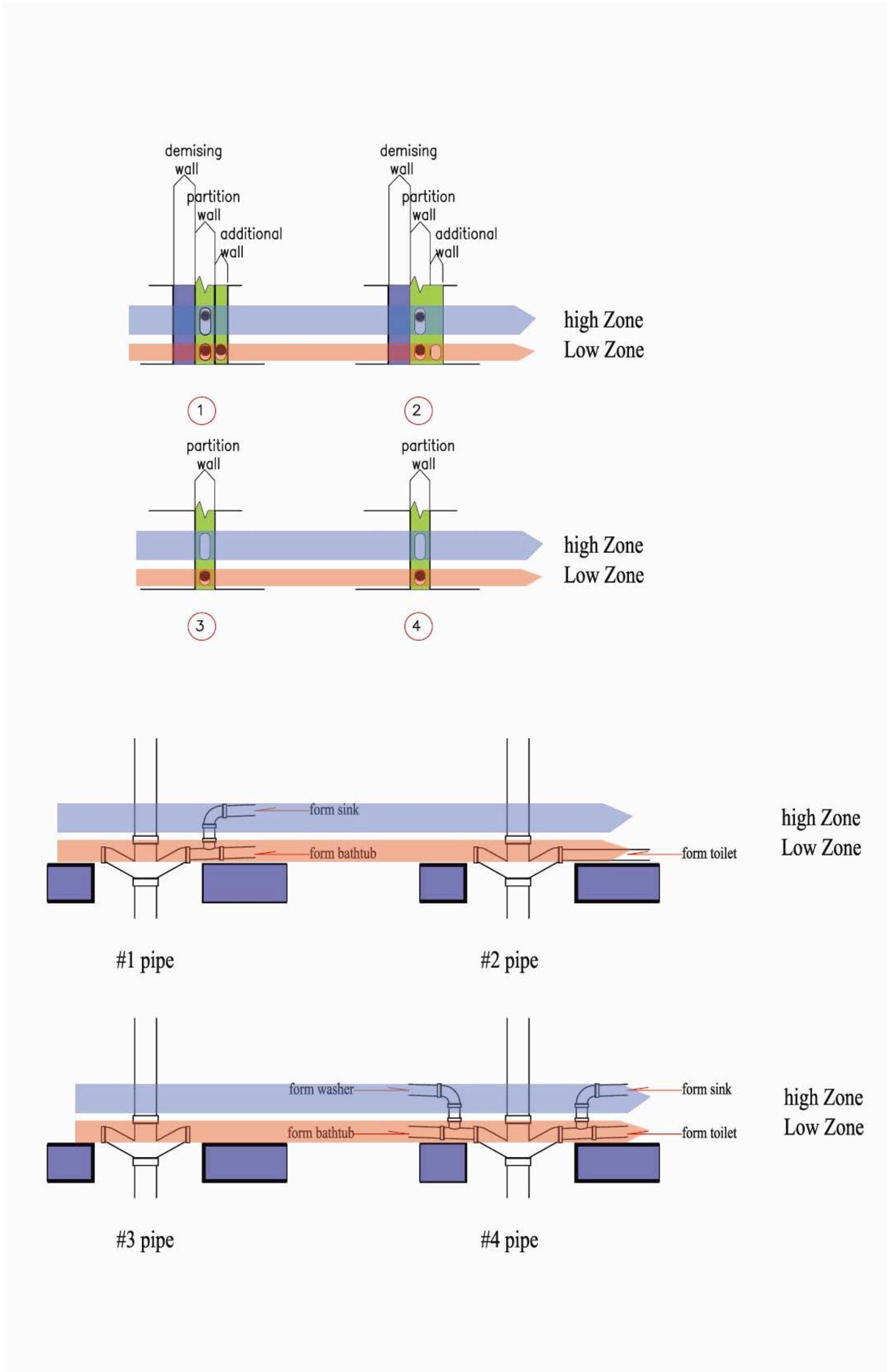


Figure IV- 8 Wall sections and MEP stack elevations.

c) **Variation B-b-1**

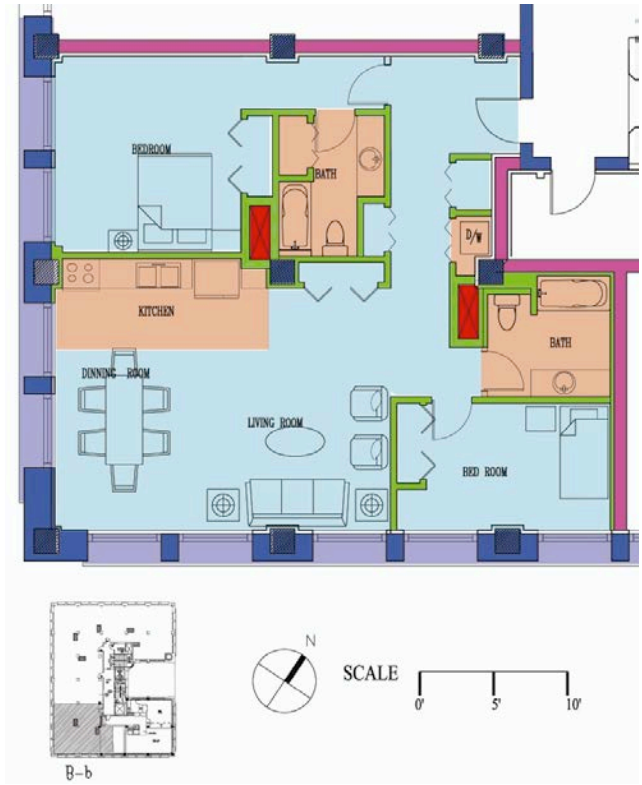


Figure IV- 9 one of the layout variations for B-b size unit

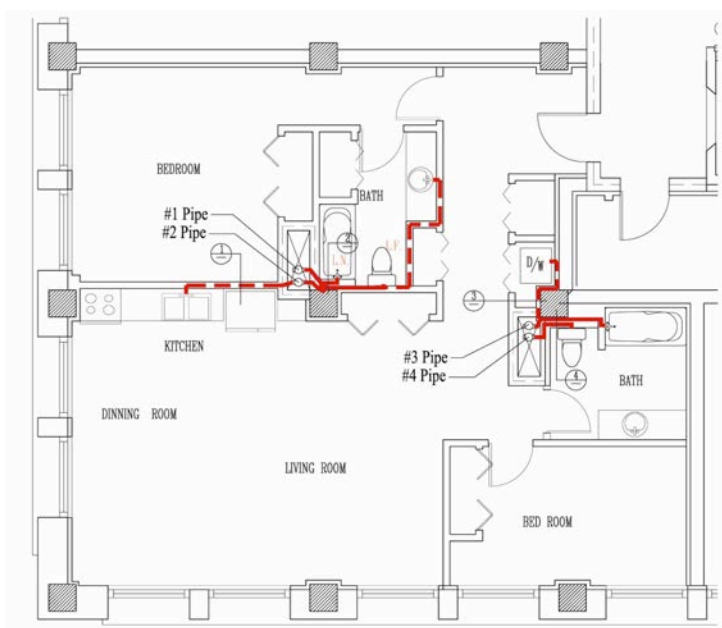


Figure IV- 10 Piping diagram for one layout of unit B-b.

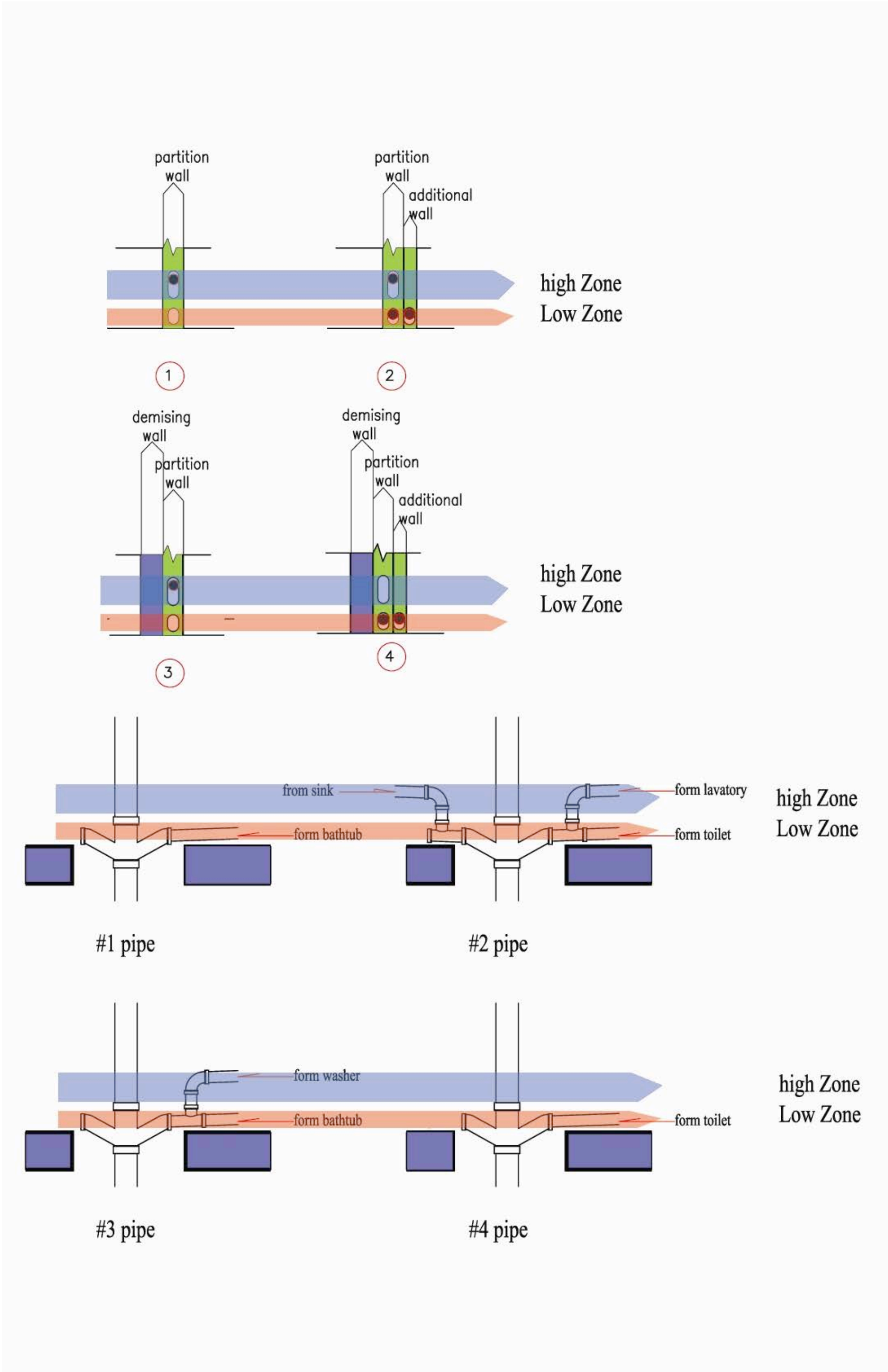


Figure IV- 11 Wall sections and MEP stack elevations.

d) Variation B-c-1

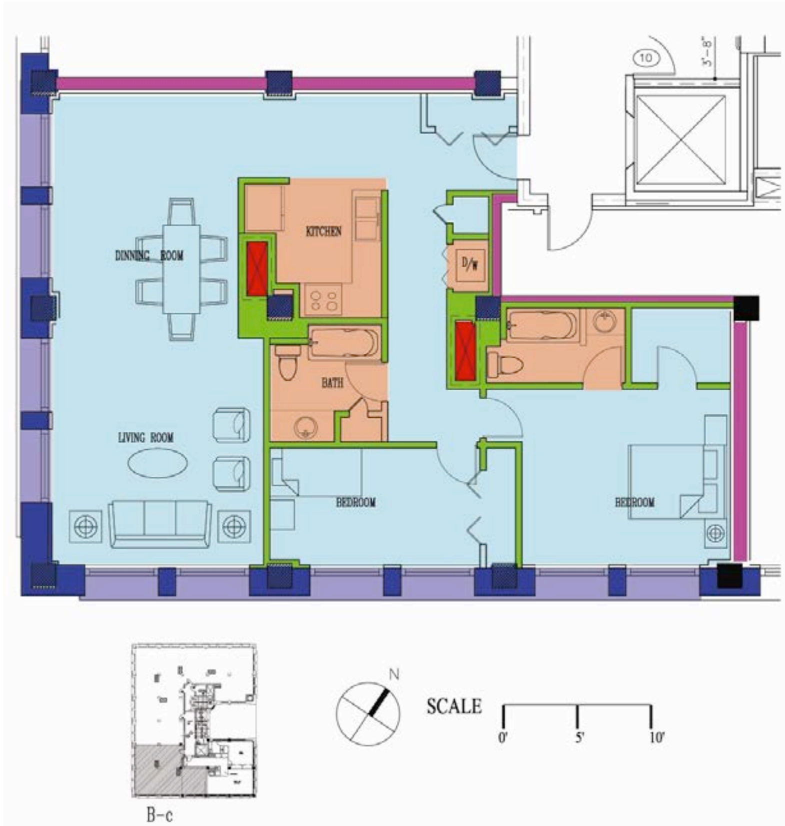


Figure IV- 12 one of the layout variations for B-c size unit

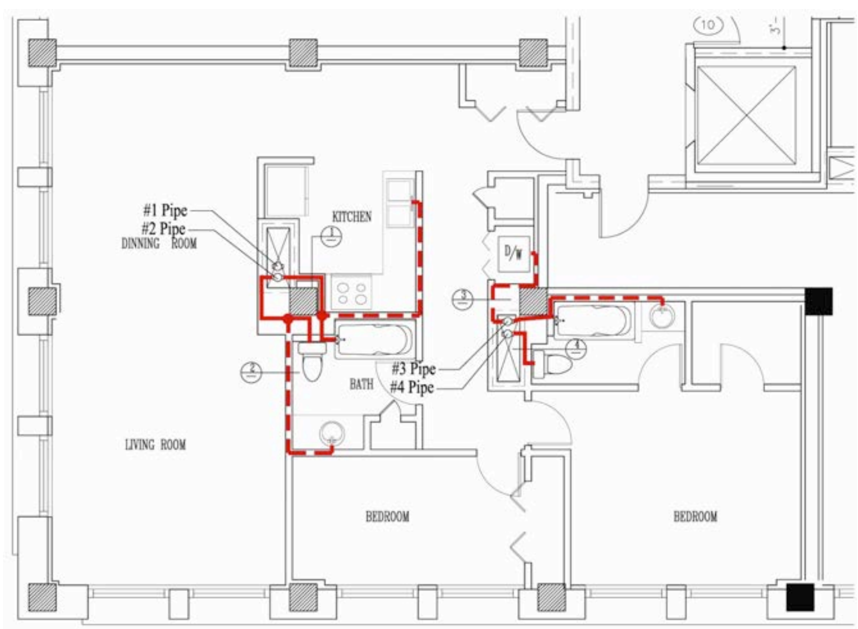


Figure IV- 13 Piping diagram for one layout of unit B-c.

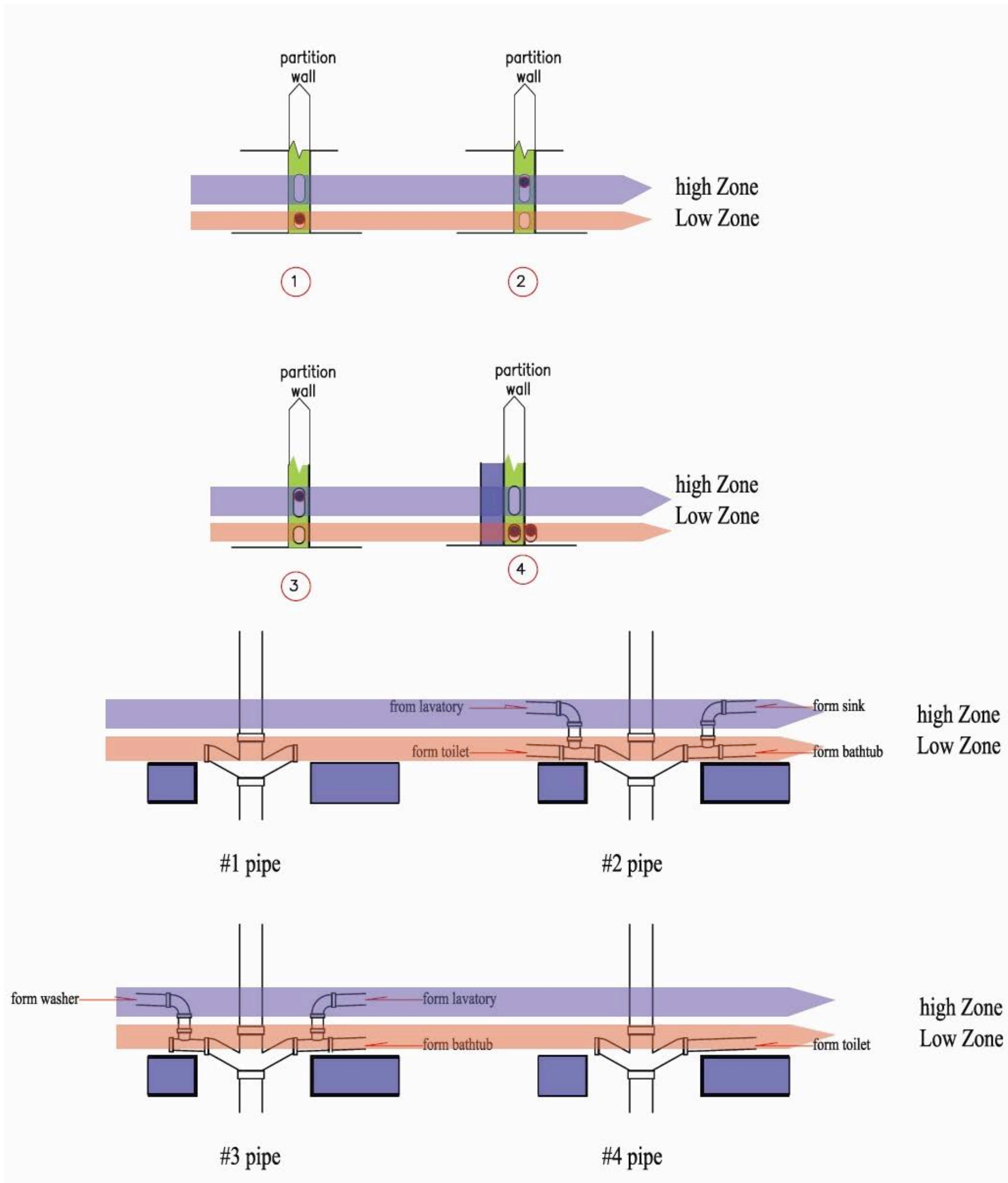


Figure IV- 14 Wall sections and MEP stack elevations.

e) Reflections

These four variations are developed by using the methods and following the technical rules that developed in the thesis. Only from the architectural layout drawings, they appear no differences to conventional high-rise residential unit layout; however, these unit layouts are developed from O.B. concept and they have some significant advantages such as offering decision deferring for developer, various unit variations for future tenants and reducing unit territory entanglements and so on, which conventional designs never can approach. All piping diagrams of each variation show how piping "traffic" organize inside the partition walls and therefore prove its feasibility in the application.

IV-3 Case study II- high-rise condominium design project

Project Location: Downtown Indianapolis, north-east intersection of Washington St. and Illinois St

Figure IV- 15 This is a site picture taken from Washington Street in downtown Indianapolis.

Project Brief Introduction:

This is a new multi-story building the lower floors (1st floor to 17th floor) of which are hotel rooms and the upper floors (18th floor to 20th floor) are residential condominium units. The design team (led by the Indianapolis firm Browning Day Mullins and Dierdorf) followed conventional practices in determining the floor plans and the technical consequences for the upper floor condominium units. These decisions were being made after the construction of the building had already started.

Figure IV- 16. The site under construction. (Taken on June 26, 2004)

Figure IV- 17. The sentence "Indianapolis' Five Star Future is Here" which indicates the building is a high standard and big budget investment project.

Figure IV- 18 One to One relationship between space plan and slab penetration

The Floor plan on the right is a preliminary concept design developed by the architect in response to the marketing advisors. The resulting floor penetrations - shown schematically in the left diagram, corresponds directly to the floor plan shown in the right diagram. In this conventional approach, the relationship between the floor plan and the "Base Building" is "one to one". Variations and future adjustments are very limited and, when attempted, cause the usual disruption and intrusion into the condominium units below.

(Source: Browning Day Mullins Dierdorf Architects)

Task: Design unit variations while maintaining "dwelling unit autonomy", thus preparing a good base building that has optimal capacity for decision flexibility in the pre-construction and construction phases, and in the future.

Methodology: Based on O.B. concepts, using the methods and technical rules (design constraints) that were developed in the thesis.

Challenge: Compared to Case Study I, the new challenges form this case study are: 1) The structural system uses cast-in-place pre-stressed slabs. Floor penetrations must be very carefully coordinated with the reinforcing cables, and the position for future penetrations is highly constrained (offering very little decision flexibility). Using OB principles, and capacity analysis, floor penetrations offer wide choice initially and later. 2) The condominium units are targeted for the luxury market. The units will have more bathrooms than Case Study #1 and they will be more luxurious in number of fixtures and amenities. This has an impact on the size and number of MEP stacks. 3). The lower levels of the building are hotel rooms, and upper layers are condominium units. There are two different set of sewage systems. Therefore, there will be a transition layer between the hotel layer and the condominium layer to align the MEP lines from the condominium layer according to the hotel drainage system.

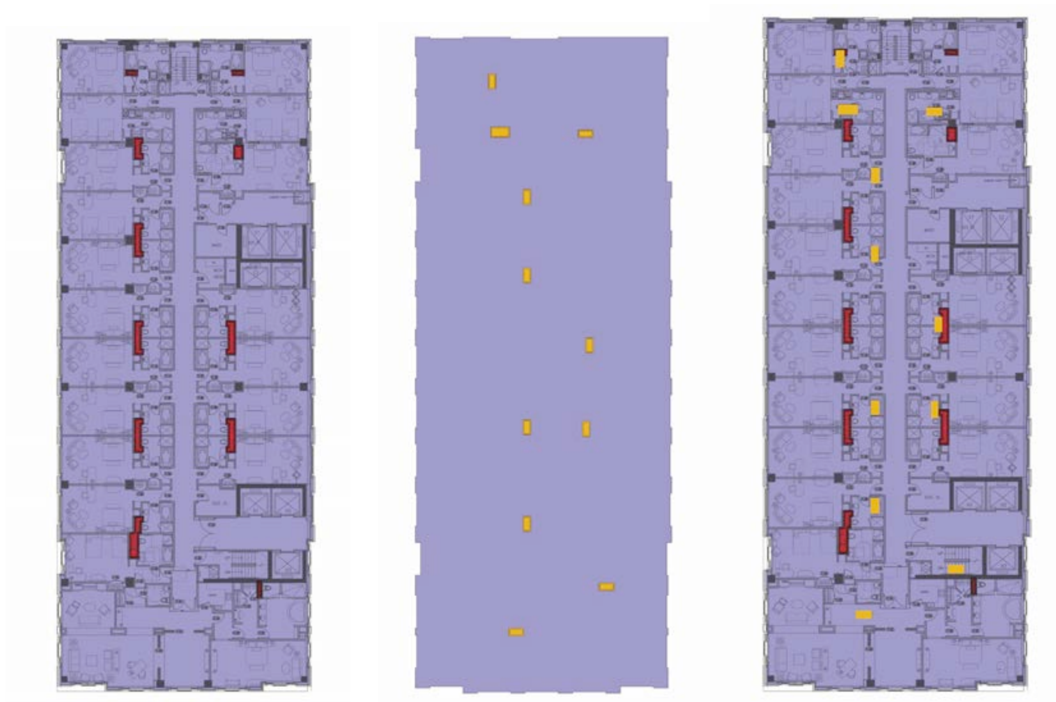


Figure IV- 19. The left diagram is the MEP locations diagram of hotel as proposed by the architect of the project. The middle one is the MEP stack locations of the condominium as proposed in this case study demonstration (not as actually being constructed). The right diagram shows the overlapping of the hotel and the proposed condominium MEP stacks.

(Source: Browning Day Mullins Dierdorf, Architects)

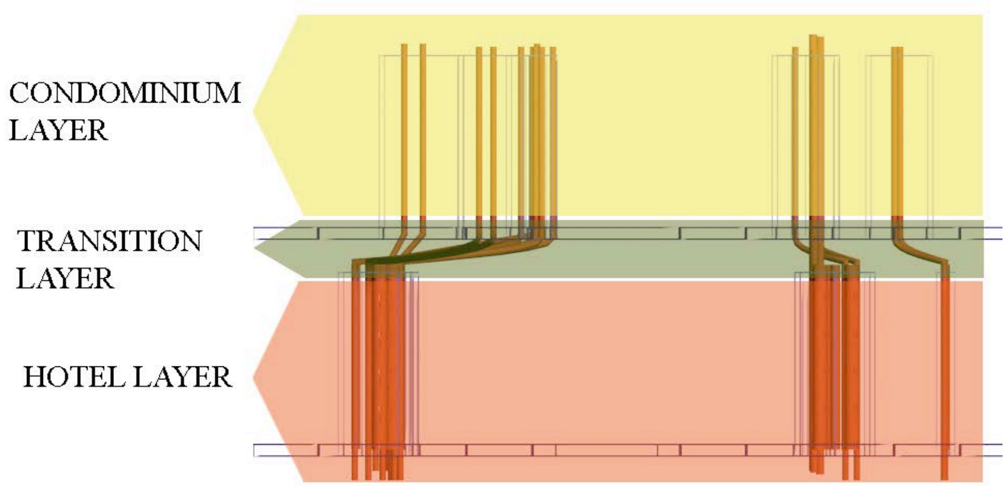


Figure IV- 20. Transition layer offers space for aligning the drainage pipes from the upper level according to the lower level.

Results: From Unit A to unit C, 20 variations are already developed; (see appendix IV for other variations) more variations can still be developed.

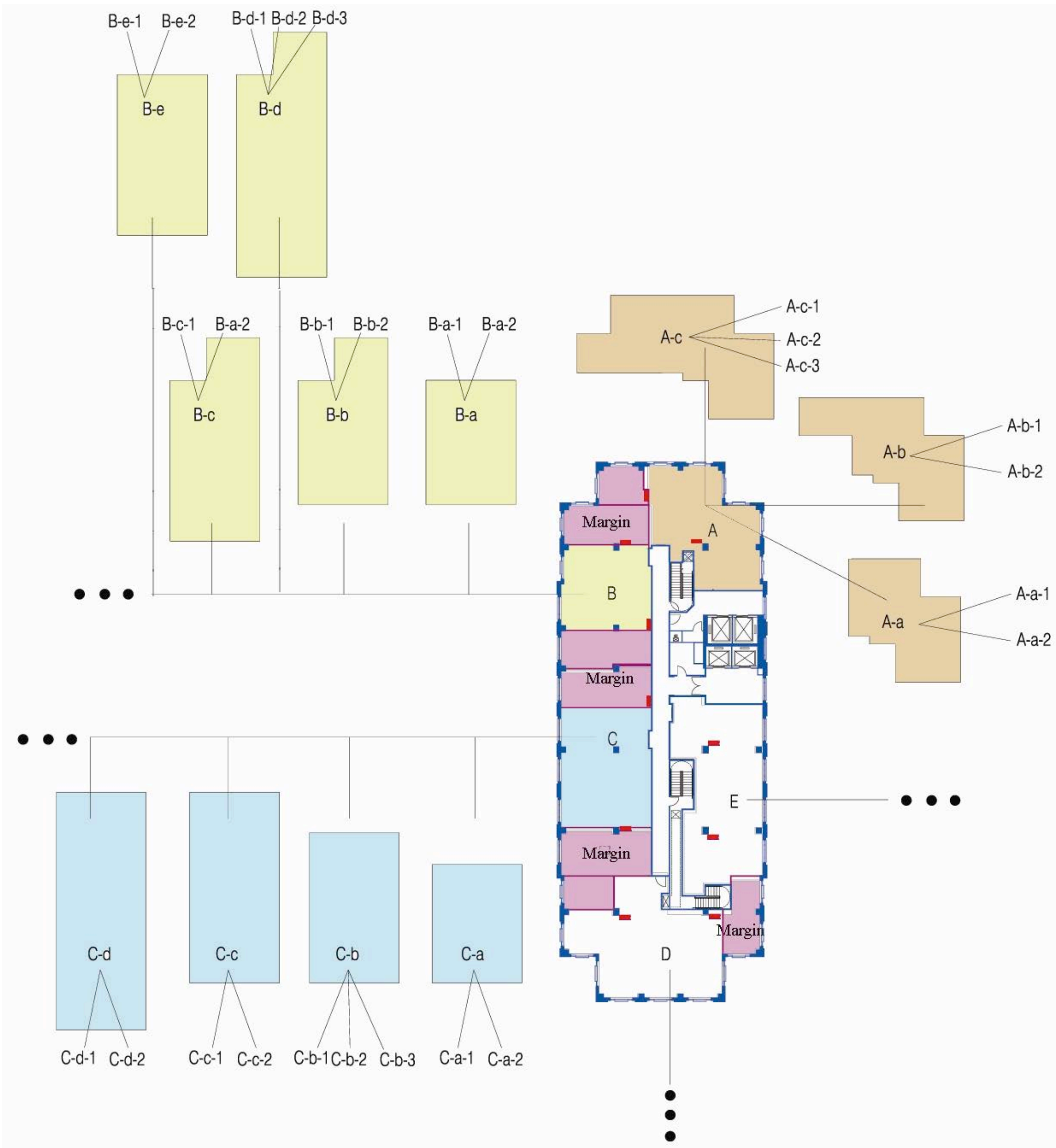


Figure IV- 21. Once the Base Building of the condominium is developed, many unit sizes can be created, and floor plan layout variations can be develop to provide more options for occupants.

a) **Variation A-a-1**

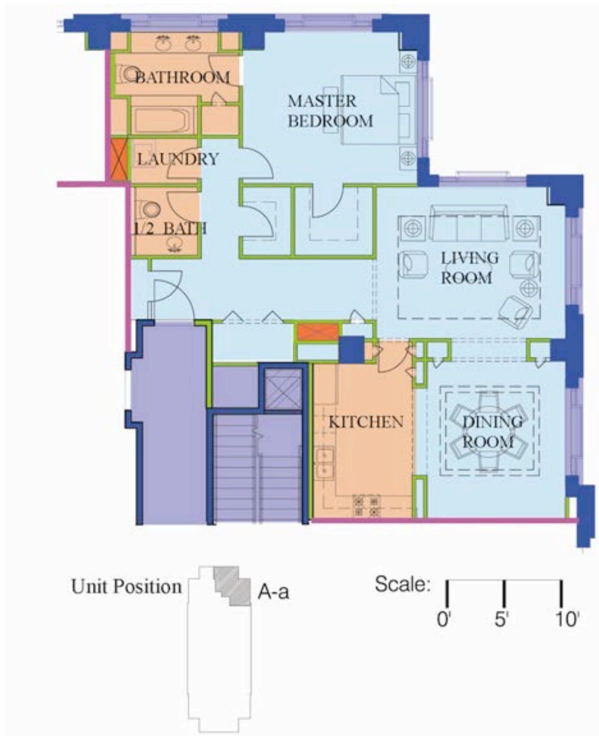


Figure IV- 22one of the layout variations for A-a size unit

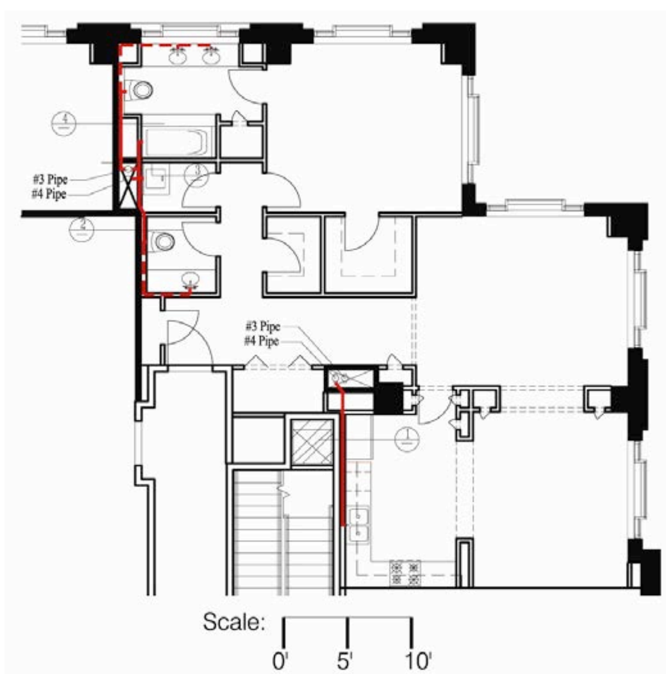


Figure IV- 23 Piping diagram for one layout of unit A-a.

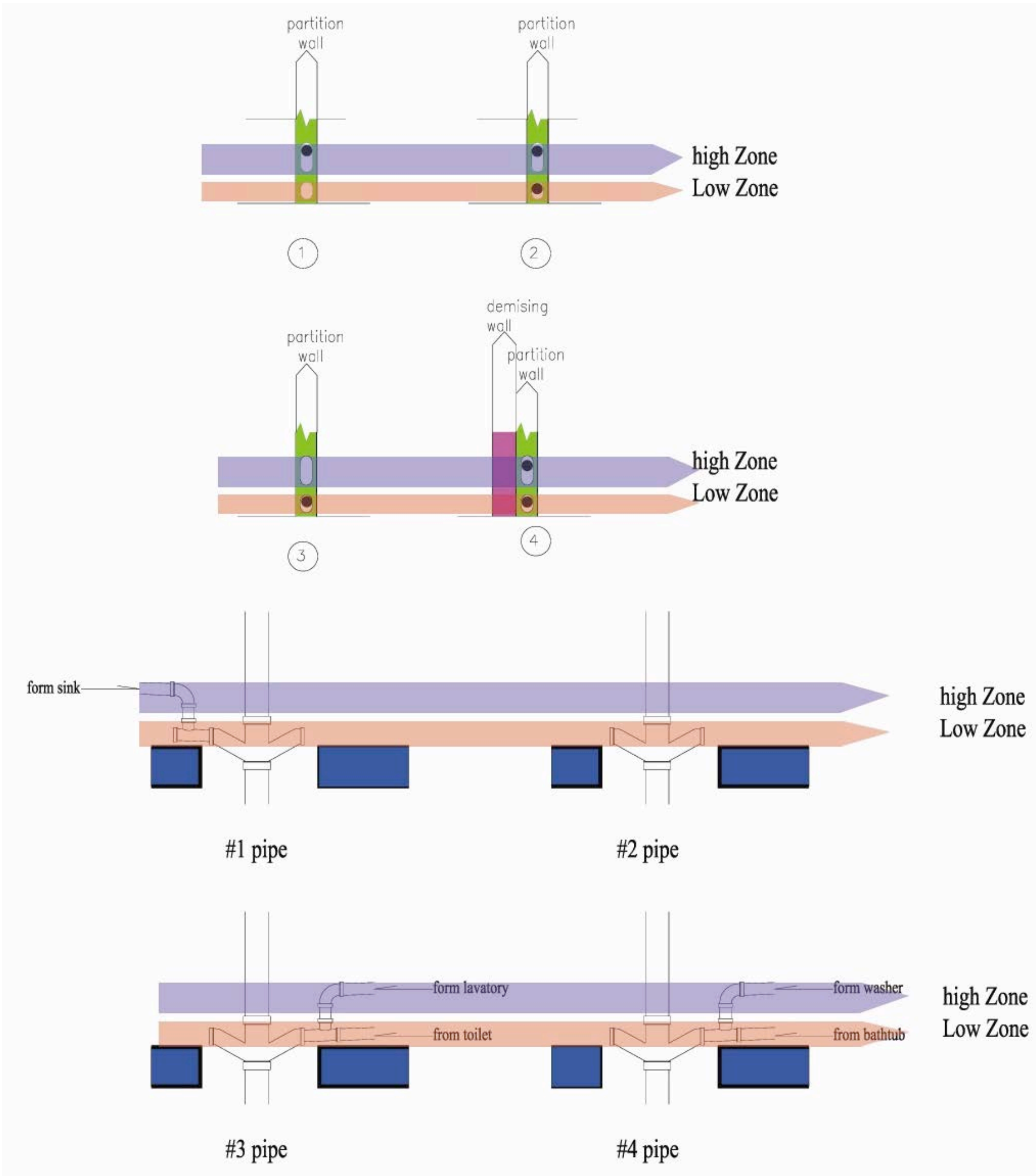


Figure IV- 24 Wall sections and MEP stack elevations.

b) **Variation B-c-2**

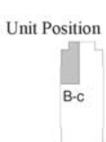


Figure IV- 25 Left:: one of the layout variations for B-c size unit

Right: Piping diagram for one layout of unit B-c.

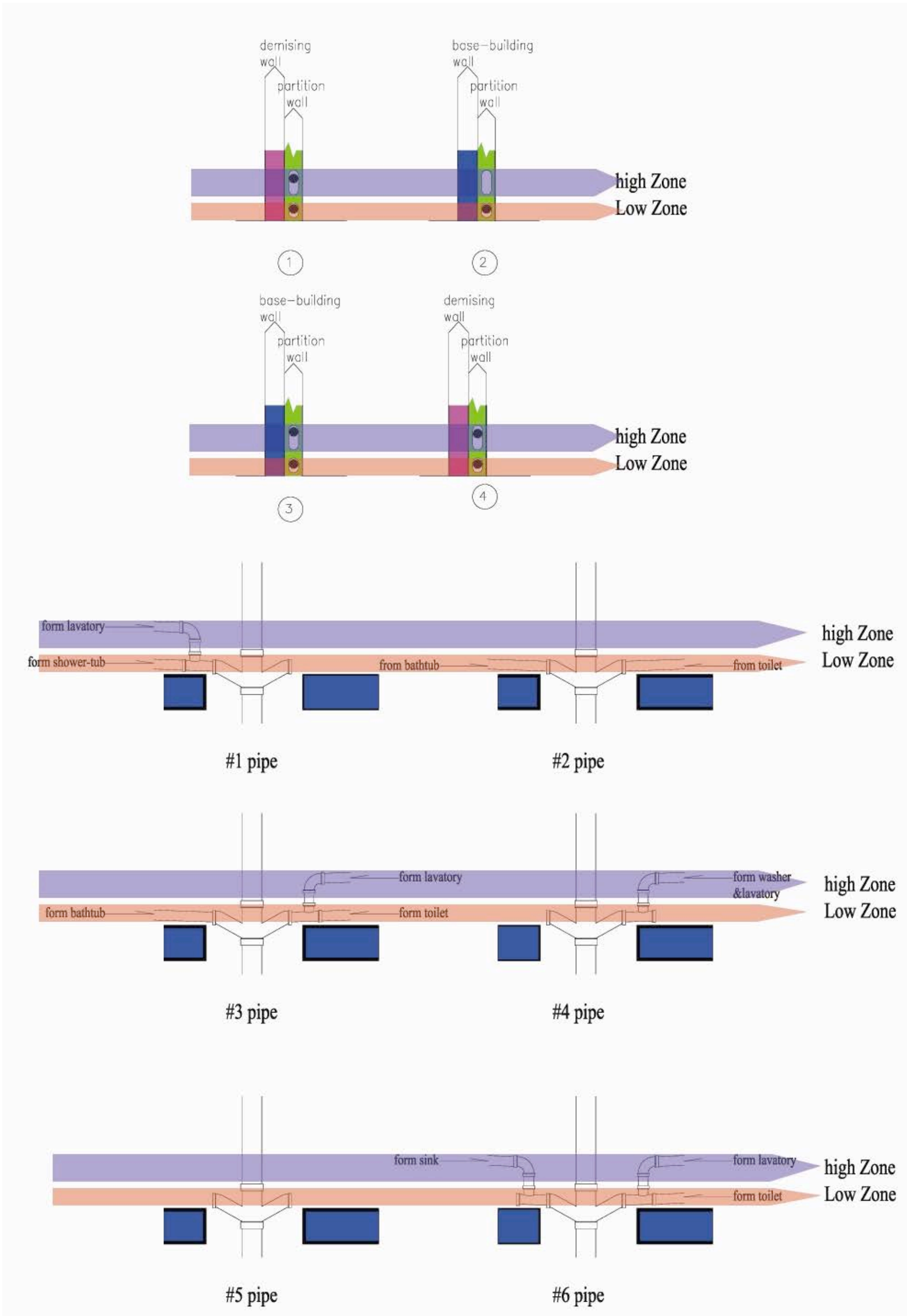


Figure IV- 26. In this diagram, #5 base building drain pipe has no pipes discharging to it. But this does not mean that #5 pipe can be omitted. Because on different floor with different variations, #5 may be have pipes discharging to it.

c) Variation C-c-1

Figure IV- 27 one of the layout variations for C-c size unit

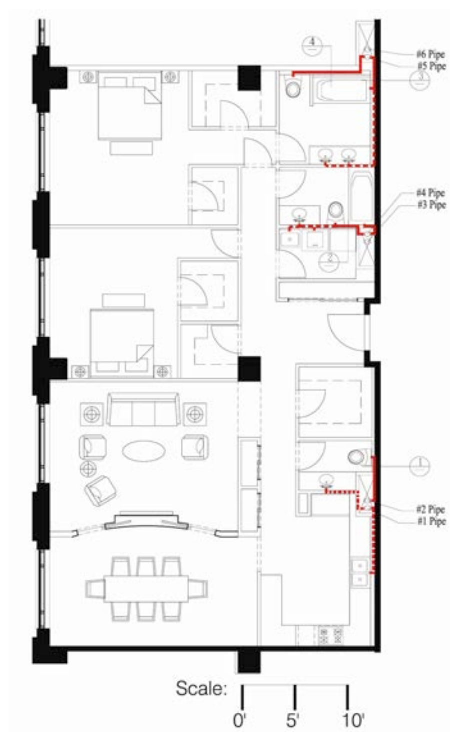


Figure IV- 28 Piping diagram for one layout of unit C-c-1.

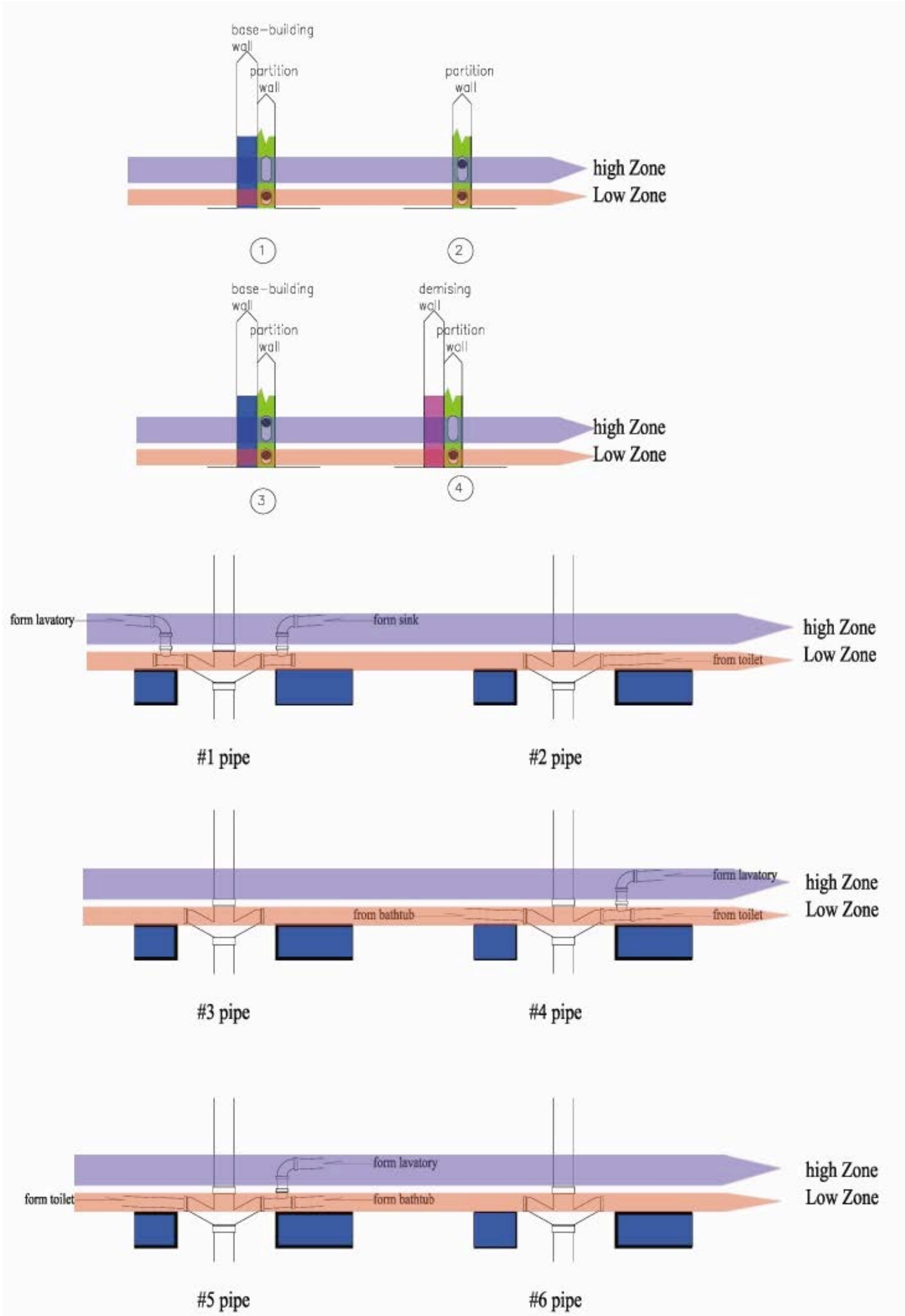


Figure IV- 29 Wall sections and MEP stack elevations.

IV-4. Conclusion & observation

This thesis has attempted to demonstrate that, compared to conventionally designed multifamily residential buildings, buildings designed following OB principles can offer certain advantages. Principal among these advantages are 1) decision flexibility for the developer during the planning, construction and occupancy phases; 2) improved design methods and means to control variation and changes for the design team; 3) pricing and construction predictability for the construction management team; and 4) choice now and in the future for tenants or inhabitants.

IV-4-1 Space comparison

In conventional buildings, drainage pipes serving fixtures of a given dwelling unit penetrate floor slabs where each individual fixture is located. From that point, they slope to an MEP stack, hidden in the ceiling of the unit below. That ceiling cavity also contains duct work, cabling, sprinkler lines and other MEP parts serving the unit below. This cavity must be of sufficient vertical dimension to contain all of these parts serving two different units. (see Figure IV-31) With this extra layer, it allows fewer MEP stacks in conventional buildings.

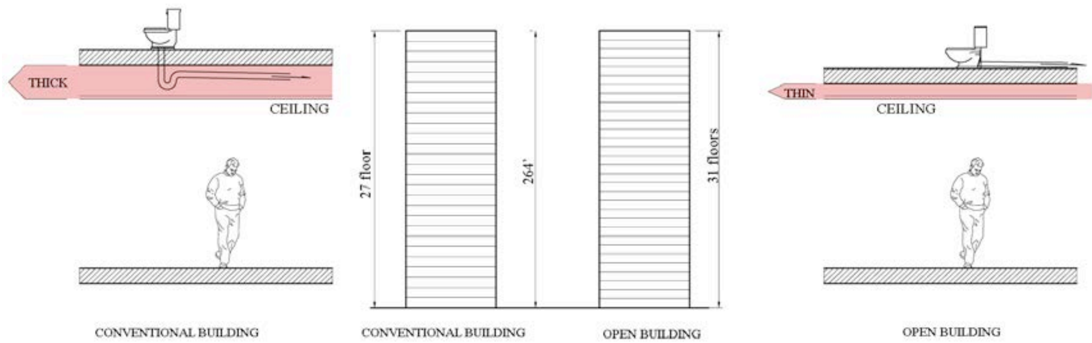


Figure IV- 30. This section diagram shows conceptually the consequences to a multi-floor building's vertical dimension of the conventional and an OB approach to horizontal drainage routing. Typically, an O.B. floor-to-floor dimension can be reduced 12-15" compared to a conventional building. Therefore, in a high-rise residential building, assuming the high of the building is 264' tall, with the same clear high for each floor, O.B can have four floors more than a conventional building which is a great advantage for the project investment. (Derived from Macsai, 1982)

In an Open Building approach, sanitary fixtures all use above floor rough-in, and drainage pipes achieve their correct slope above the unit floor inside that unit's infill partition walls. (Figure IV-30 right).Because the fixtures in LDZ present more constraints, some drainage pipes require additional walls. But these walls do not need to be full floor high. They can be in various heights depending on different circumstances. For instance, an additional wall can stop and align to the top of a bathtub to enlarge its edge where objects can be placed.

Nevertheless, according to O.B. concept, drainage pipes can not run into the demising walls which belong to the base building. Additional walls should be placed parallel to these demising walls when pipes need to go along any demising walls.

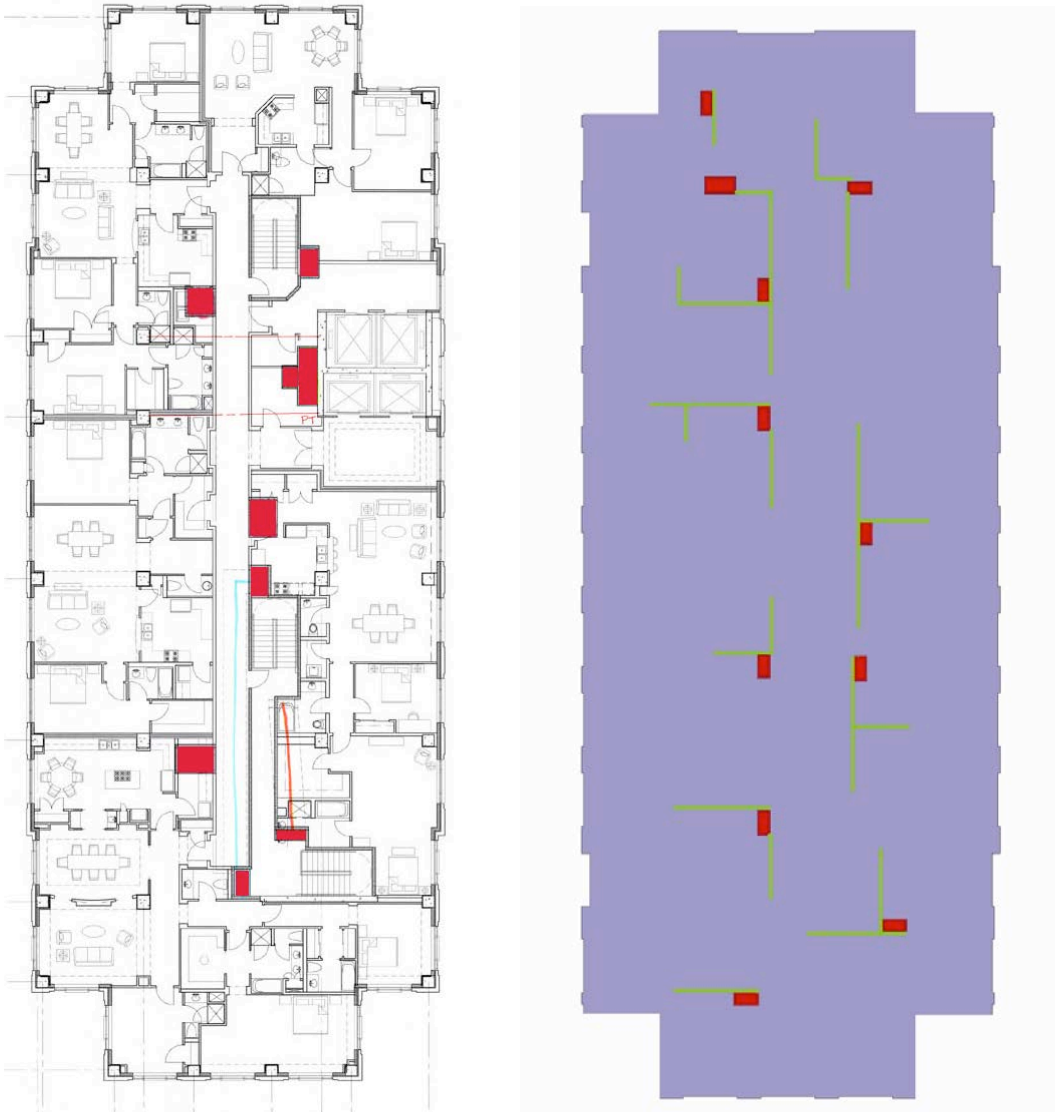


Figure IV- 31. The left diagram shows the MEP stack locations and sizes in a conventionally designed building. The red rectangles in the right diagram are the MEP stacks placed using capacity analysis. The green lines indicate "additional" walls needed for horizontal drain lines, parallel to the 'normal" space dividing infill walls.

(source: Browning Day Mullins Dierdorf Architects)

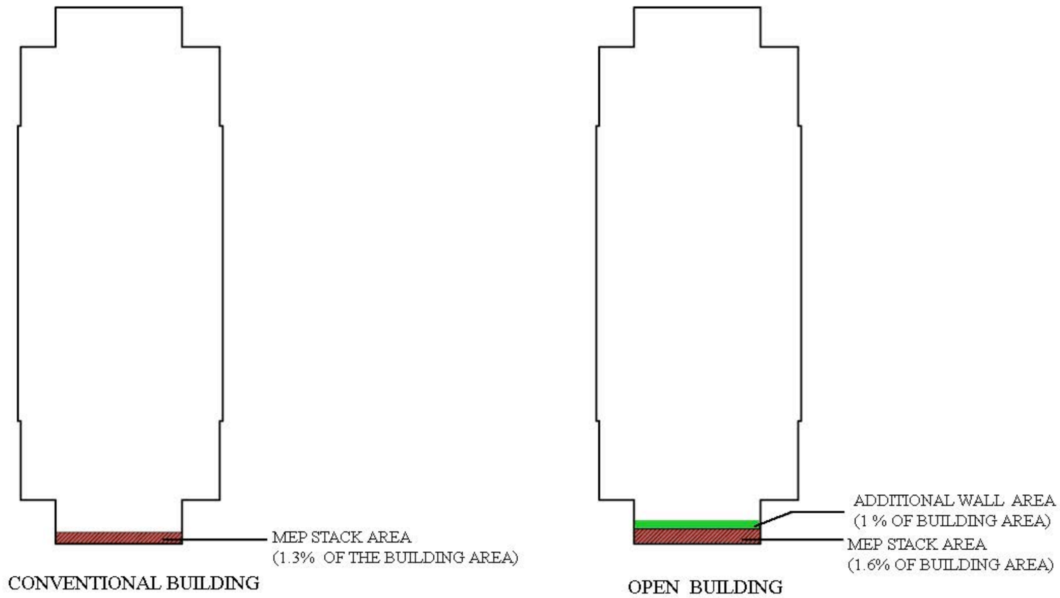


Figure IV- 32. Using the second case study (the Hotel/Condominium project) as an example, this is a comparison of the floor area required for the "additional" walls (see Figure IV-32) of an OB approach compared to a conventional building.

IV-4-2 Decision flexibility and Unit Variation

The two case studies are presented as demonstrations of the use of OB principles and methods (such as the plumbing related design constraints developed in this thesis) in achieving decision flexibility and unit variation. If a "base building" is designed well, many unit variations can be provided (see P84 Figure IV-2 and P104 Figure IV-21). There are usually more than two alternative variations in a given size unit. On the other hand, in conventional buildings, the relationship between base building and layout floor plan is basically "one to one". This means that a dependency relation is normally established that produces conflict, waste, legal conflict and excessive costs. Avoiding this is the key objective of using open building methods. Other variations can neither develop nor functionally works.

IV-4-3 Legal entanglement issue

In conventional high-rise residential buildings, rearranging a floor plan layout after other units are occupied requires agreements to be reached between the unit in question, the party controlling the base building, and the owner/occupant of the unit in whose ceiling the piping is routed (as described above). This often results in conflict, because a change of one unit necessitates entering another unit's space to do the work. For example, when the drainage pipe of the upper floor leaks, it causes damages for the lower floor ceiling. Another example - one that does not involve adjustments to space layout - is related to sound: it is annoying that the sound of flushing toilet can be heard in the lower floor. It seems a phenomenon that one has to accept all these problems before moving into multi-story residential building. However, by making technical decisions in respect to an understanding of "territory" and "control", this thesis hopes to have shown that by using OB processes, design teams can avoid all the issues mentioned above. Occupants can make decisions as they want "behind their front door" They can rearrange their unit to suit their preferences and budgets, and in any period without crossing boundaries. This same capability is available to the building owner in the case of a rental project.

CHAPTER V

Conclusion

This thesis has focused on the development of design constraints for use in analyzing the capacity of the residential units' floor plan layouts in Open Building projects. Plumbing systems, which are one of the most significant barriers to the application of Open Building, are specifically and deeply studied in this thesis. A series of constraints have been developed which can generally assist designing and analyzing floor plate capacity. During the plumbing study, LDZ fixtures presented many difficulties in approaching the criteria set for the research. Research focused on looking for available products in the US market. Technical performance and features of these fixtures have been carefully studied to seek ways for problem solving.

On the other hand, because of constraints from the physical world and lack of available products, a few criteria that were set before the study began in detail in fact cannot be accomplished. Hopefully they can be solved in the near future with new products and techniques. For instance, separating gray water and black water in two drainage systems enabling gray water to be re-used after treatment is one of the criteria that were set initially before the plumbing study. However, by using the present technique and products, it is impossible in the LDZ for horizontal gray water and black water pipes to cross each other to reach separate vertical discharge pipes in the MEP stack. Therefore, vertical drainage pipes can not be specified to carry only one kind of water - they have to accept both black and gray water. Thus, the criteria of separating black water and gray water was abandoned.

The thesis is concerned with design methods and their application in detail. It is a study of methods and technical rules (among many kinds of rules or design constraints) of designing floor plan layouts when capacity analysis is the aim. Hopefully, these methods and technical rules will be of value to those design teams who may be interested in getting into this field.

Appendix I: a new product study

It is important to find products which can solve the problems presented by OB implementation. On the other hand, in order to make this OB implementation more feasible in an industry reluctant to use unfamiliar products, one of the criteria of this study is to use products widely available in the US market and that meet the Building Codes. Suitable products were found but either are not available in the US market or do not meet the Building Codes. Among those products, HepvO is one of the most remarkable one that can contribute to this study but it has not been approved in the US at this time.

Figure API- 1 The HepvO product (up) and its operation theory (below).

(Source: www.hepvo.com/productions/10563.pdf)

HepvO is an "in-line trap" product that can replace U-trap in drainage piping installation.

One of the intentions of using U-traps is to prevent the escape of foul sewer air from waste discharge systems. HepvO is a self sealing valve designed to close the waste connection below a sanitary appliance to prevent the escape of foul sewer air into the dwelling (HepvO technical design guide). Therefore, both traditional U-trap and HepvO have the same function. However, a typical U-trap is typically 5” in height which causes difficulties for installing bath-tub or shower-tub following O.B. principles. According to the product specification, the HepvO is more efficient than traditional water seal traps or 'U' bends and eliminates the associated constraints on installation. The valve utilizes a specially-designed membrane set in a slim, white polypropylene tube. The membrane is opened when water passes through it but, once the flow ceases, it closes to create an airtight seal.

The most attractive advantage of the HepvO is its 3”thickness. From this volume advantage, if HepvO can be applied in O.B. projects, bath-tub and shower-tub can be installed lower to the floor (close to conventional heights). A comparison diagram shows the difference between a standard U-trap and HepvO. (Figure API-4&5) However, this product is not been authorized in the US yet, only in European countries.

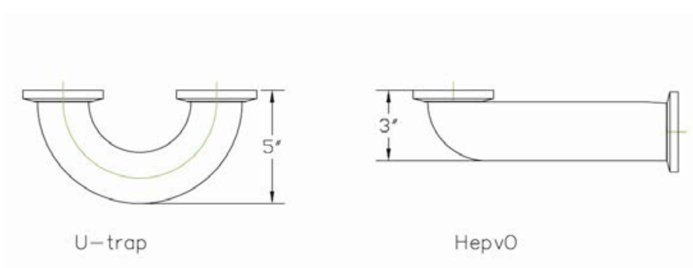


Figure AP- 2 the height dimension between a U-trap and a HepvO, as shown in the diagram, a U-trap requires at least 5” space, but a HepvO only needs 3”.

Figure AP- 3 installation of a HevpO is simple and space saving.

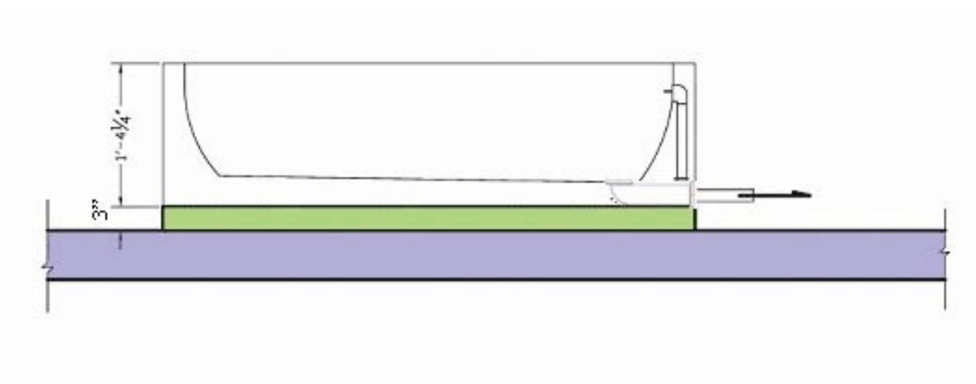


Figure AP- 4 Using a HepoV to replace of a U-trap can reduce the elevation of a bath-tub from 5" to 3". It causes the elevation more acceptable and easy to operate. However, this product is not approved and opened in the US market.

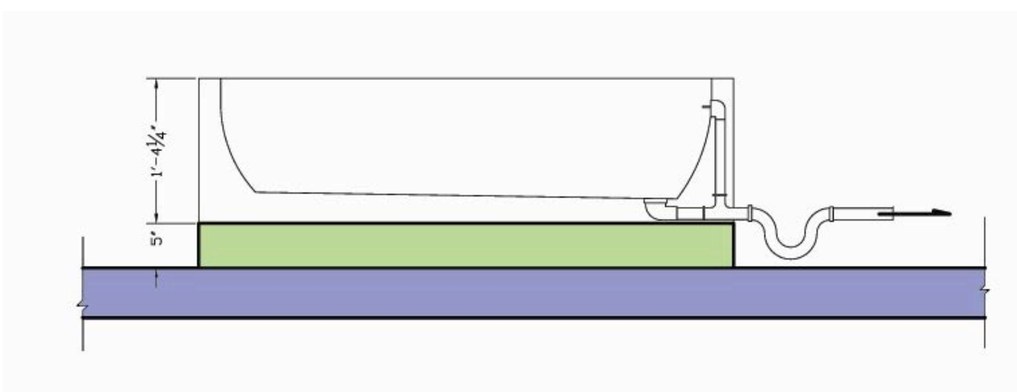


Figure API- 5 The bath-tub is raised up 5" to get enough space to install a U-trap and correct slope to the plumbing stack nearby.

Appendix II: Recommended Varied Layouts of Different Size Rooms

The study of layout floor plans in different size is one of the essential steps in capacity analysis. Before and during this study, the layouts different size of rooms have been studied, intern of living (& dining) room, bedroom, master bedroom, kitchen and bathroom. However, these recommended varied floor plan layouts are not rules that one should follow. Instead, they provide general solutions in doing floor plan capacity analysis in different circumstances.

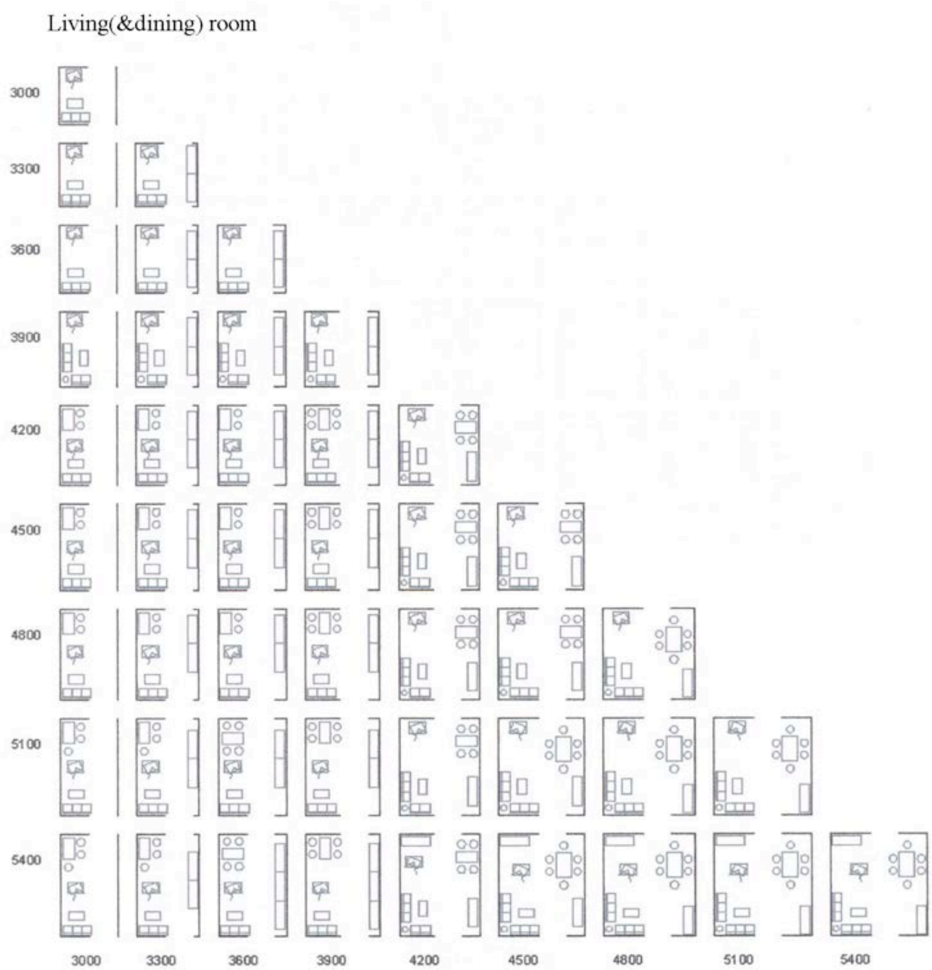


Figure AP- 6 Living and dining room variations study diagrams.

(Source: Yiwei Liu, 2000)

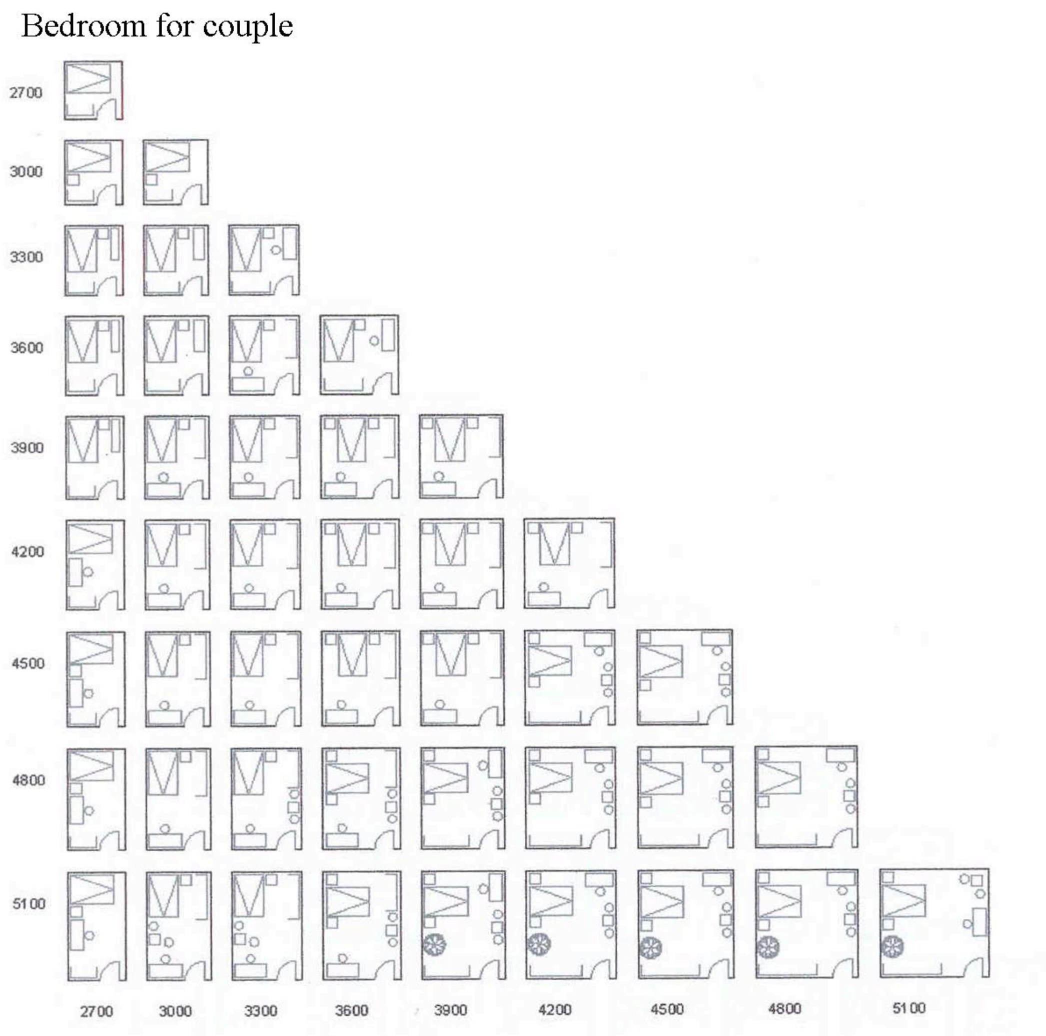


Figure AP- 7 Bedroom for couple variations study diagrams.

(Source: Yiwei Liu, 2000)

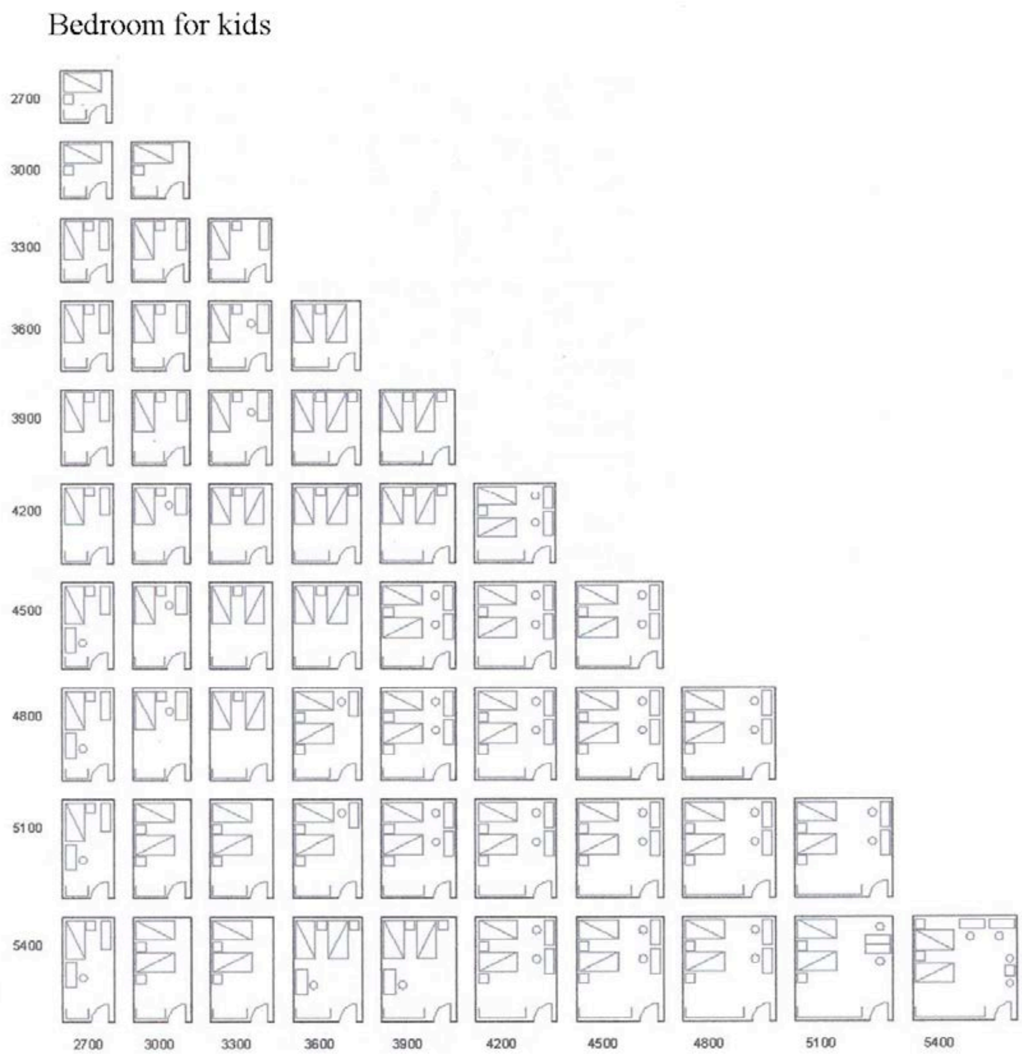


Figure AP- 8 Kids' bedroom variations study diagrams.

(Source: Yiwei Liu, 2000)

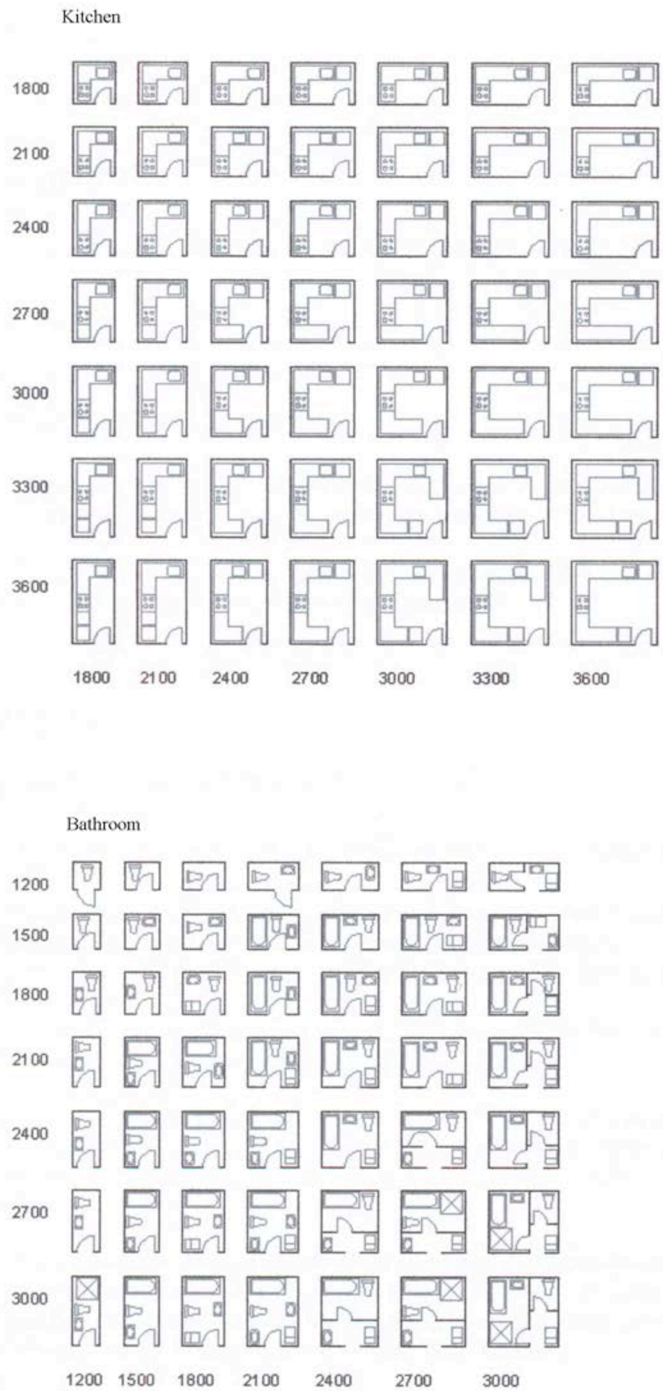
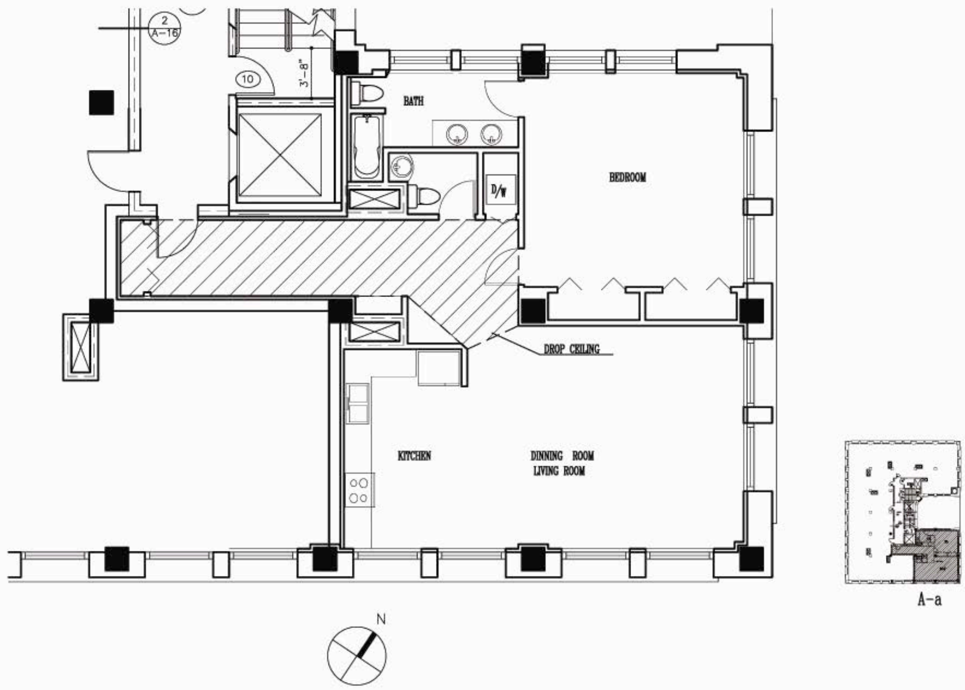
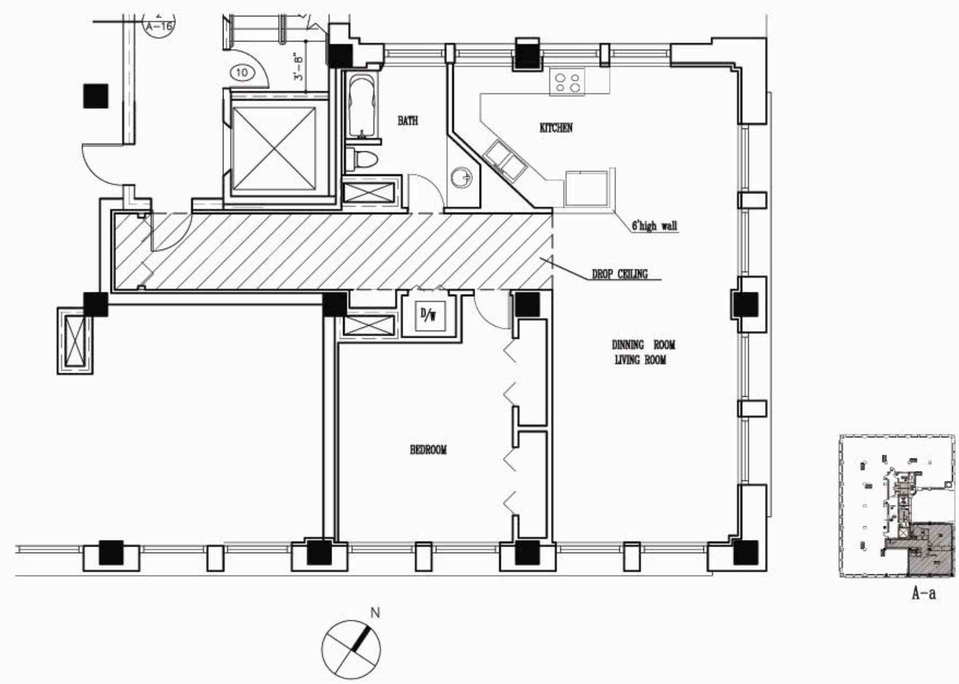


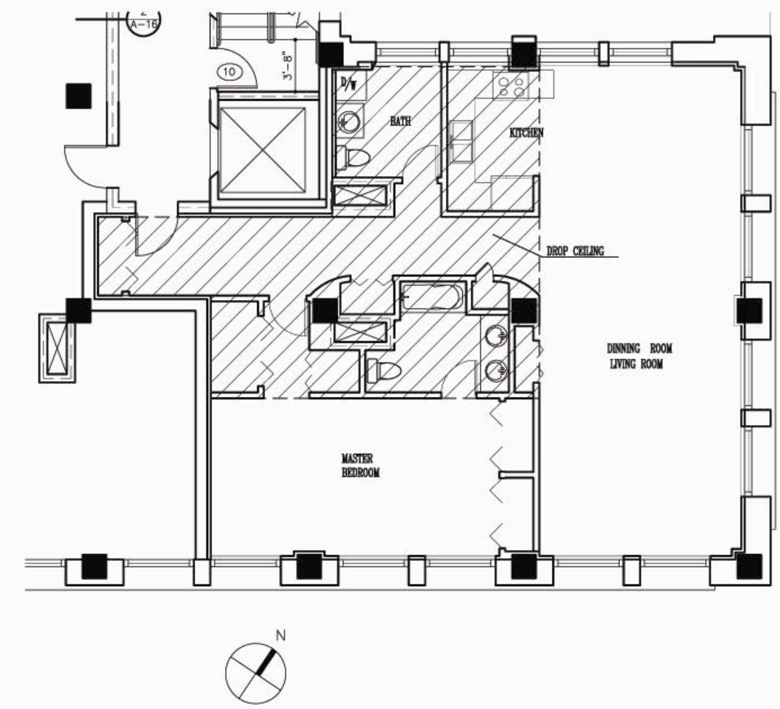
Figure AP- 9 Kitchen and bathroom variations study diagrams.

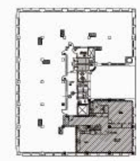
(source: Yiwei Liu, 2000)

Appendix III: Unit Floor Plan Layout variations of Case Study I

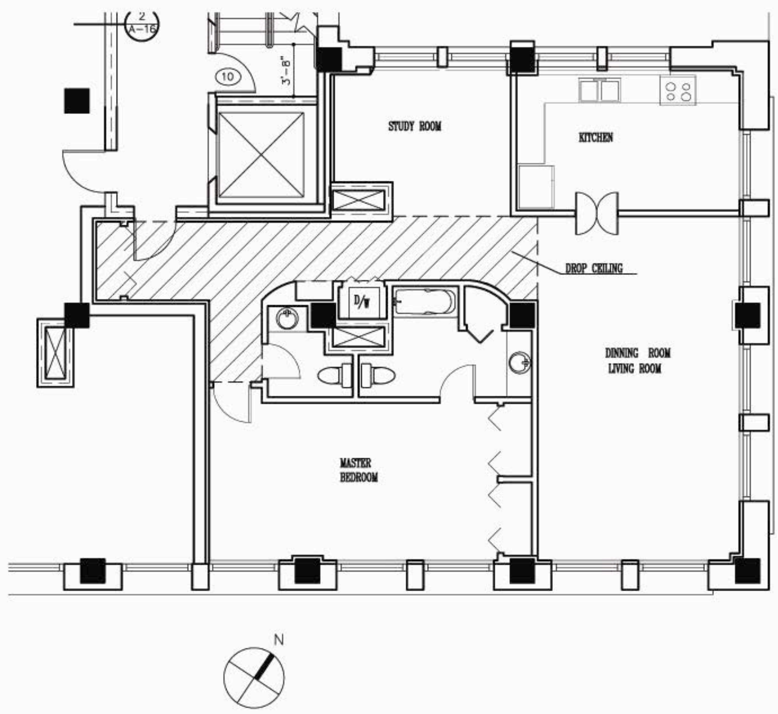


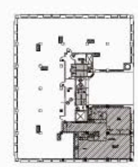



2
A-16
10
3'-8"
D/W
BATH
KITCHEN
DROP CEILING
DINNING ROOM
LIVING ROOM
MASTER
BEDROOM
N

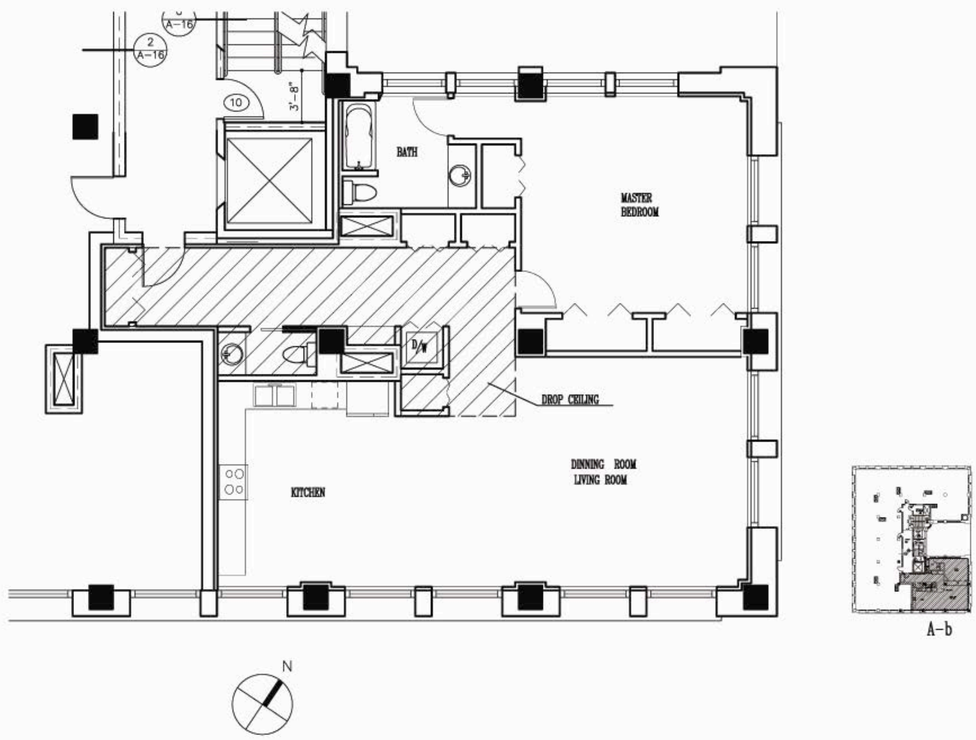


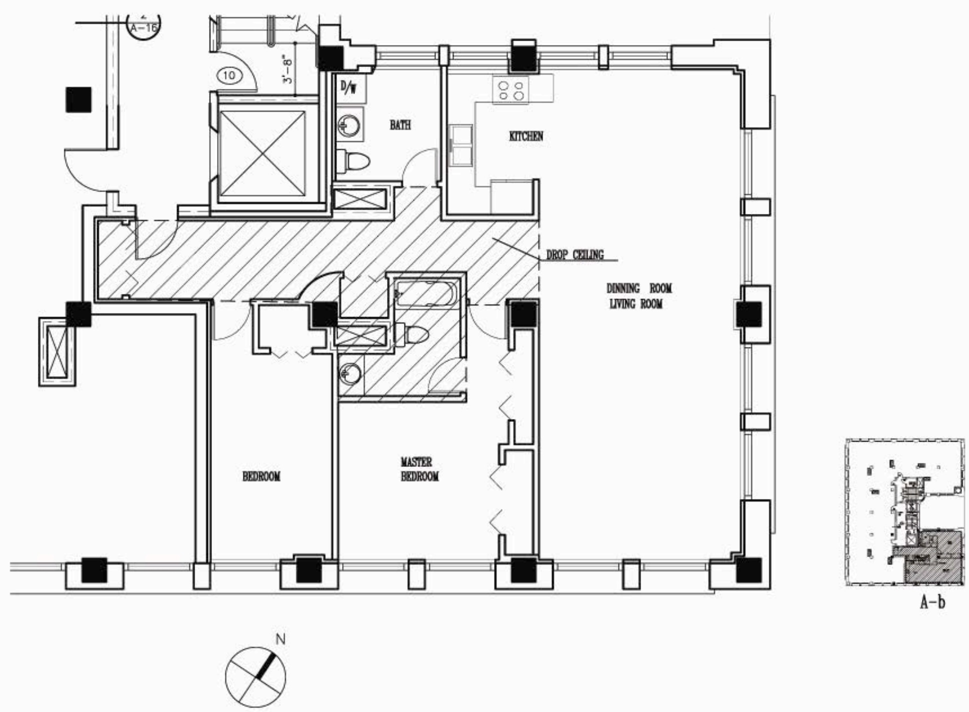
A-b

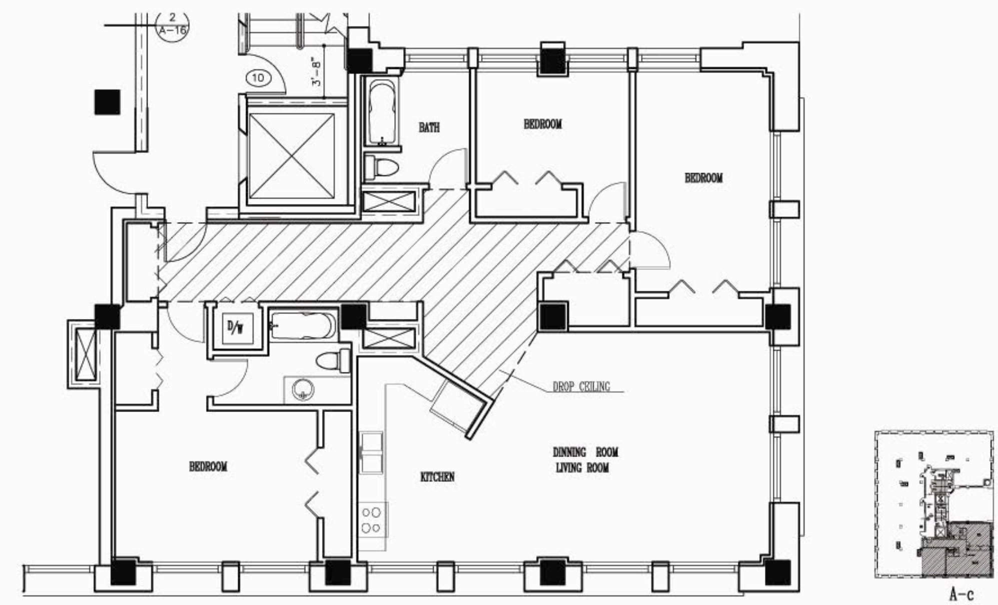

2
A-16
10
3'-8"
STUDY ROOM
KITCHEN
DROP CEILING
D/W
DINNING ROOM
LIVING ROOM
MASTER
BEDROOM
N

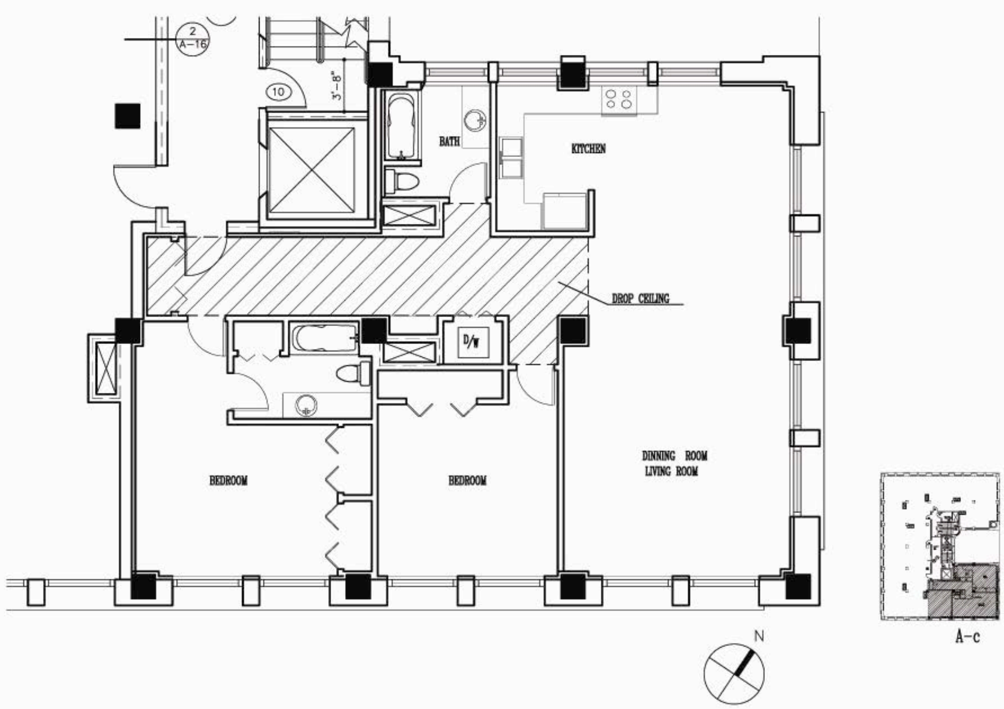


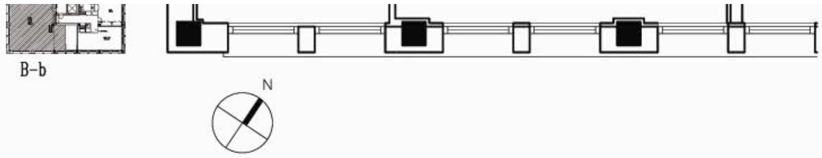
A-b

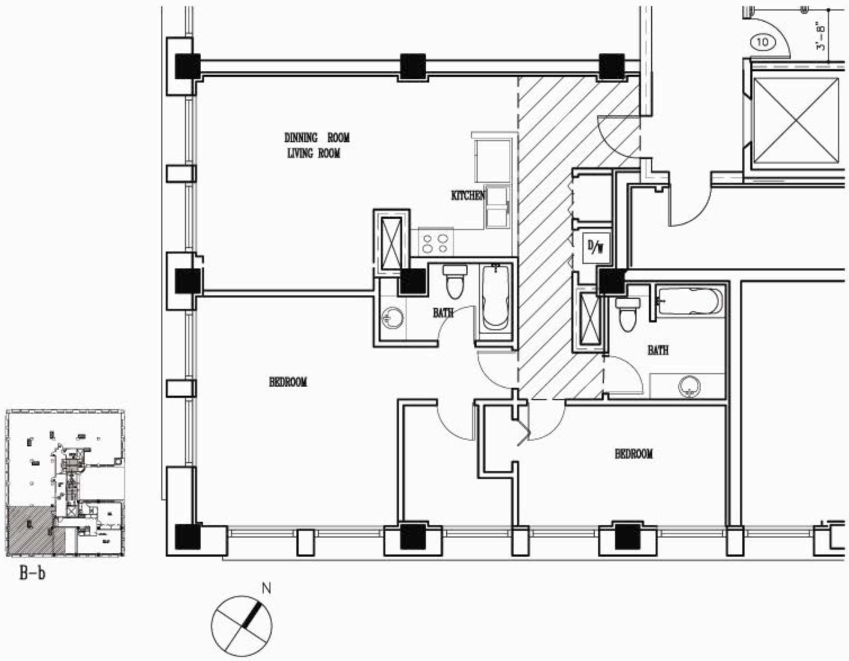

2
A-16
A-16
10
3'-8"
BATH
MASTER
BEDROOM
D/W
DROP CEILING
DINNING ROOM
LIVING ROOM
KITCHEN
N
A-b

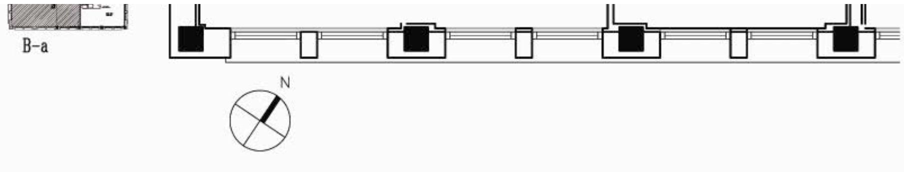

2
A-16
10
3'-8"
D/W
BATH
KITCHEN
DROP CEILING
DINNING ROOM
LIVING ROOM
BEDROOM
MASTER
BEDROOM
N
A-b

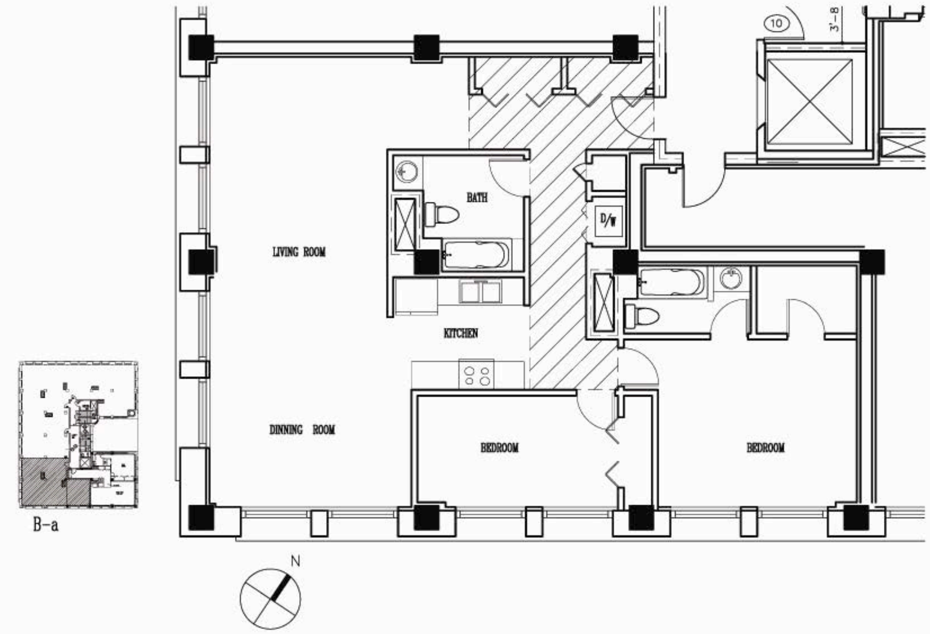

2
A-16
10
3'-8"
BATH
BEDROOM
BEDROOM
D/W
DROP CEILING
BEDROOM
KITCHEN
DINNING ROOM
LIVING ROOM
A-c

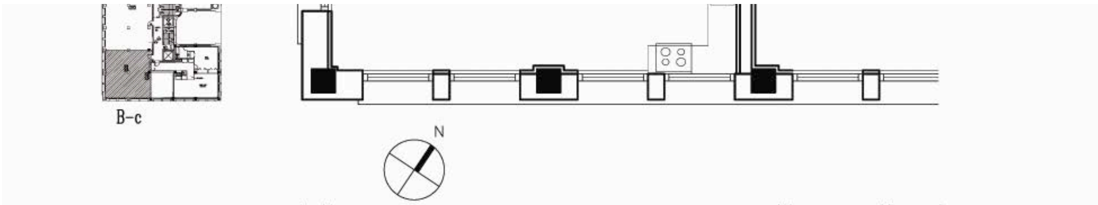

2
A-16
10
3'-8"
BATH
KITCHEN
DROP CEILING
D/W
DINNING ROOM
LIVING ROOM
BEDROOM
BEDROOM
N
A-c

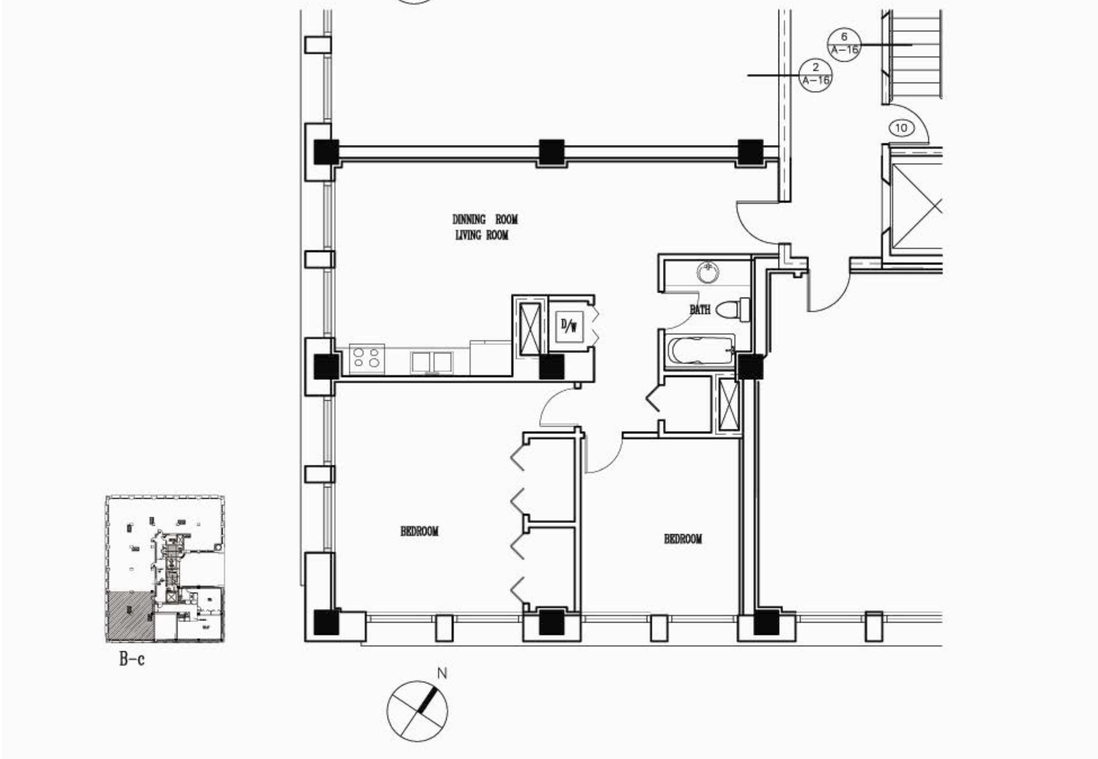

B-b
N

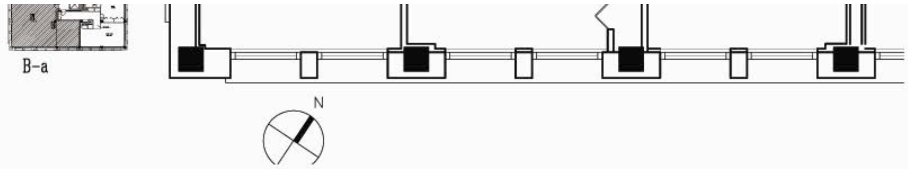

DINNING ROOM
LIVING ROOM
KITCHEN
D/W
BATH
BATH
BEDROOM
BEDROOM
10
3'-8"
B-b
N

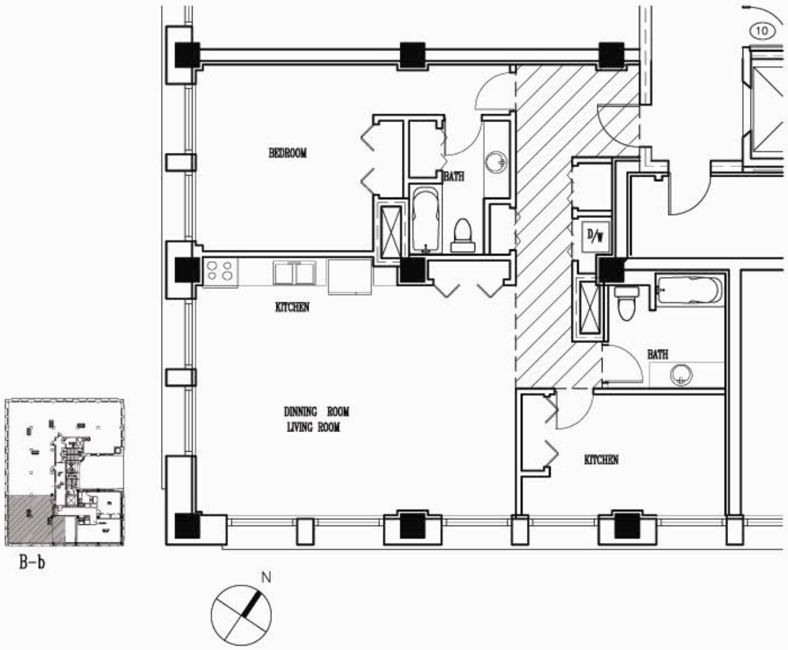

B-a
N

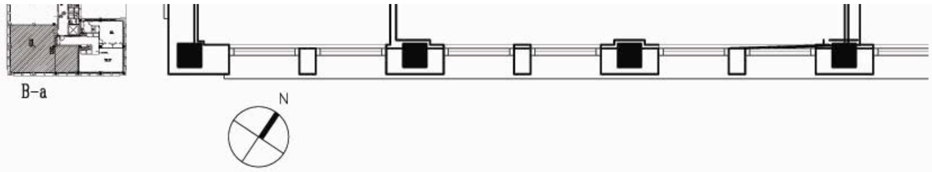

10
3'-8
BATH
D/W
LIVING ROOM
KITCHEN
DINNING ROOM
BEDROOM
BEDROOM
B-a
N

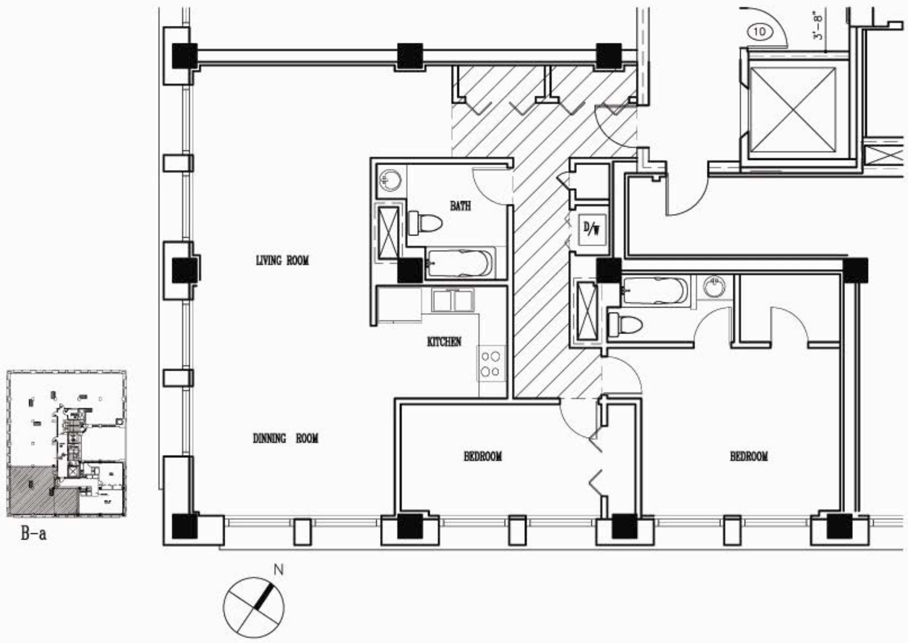

B-c
N

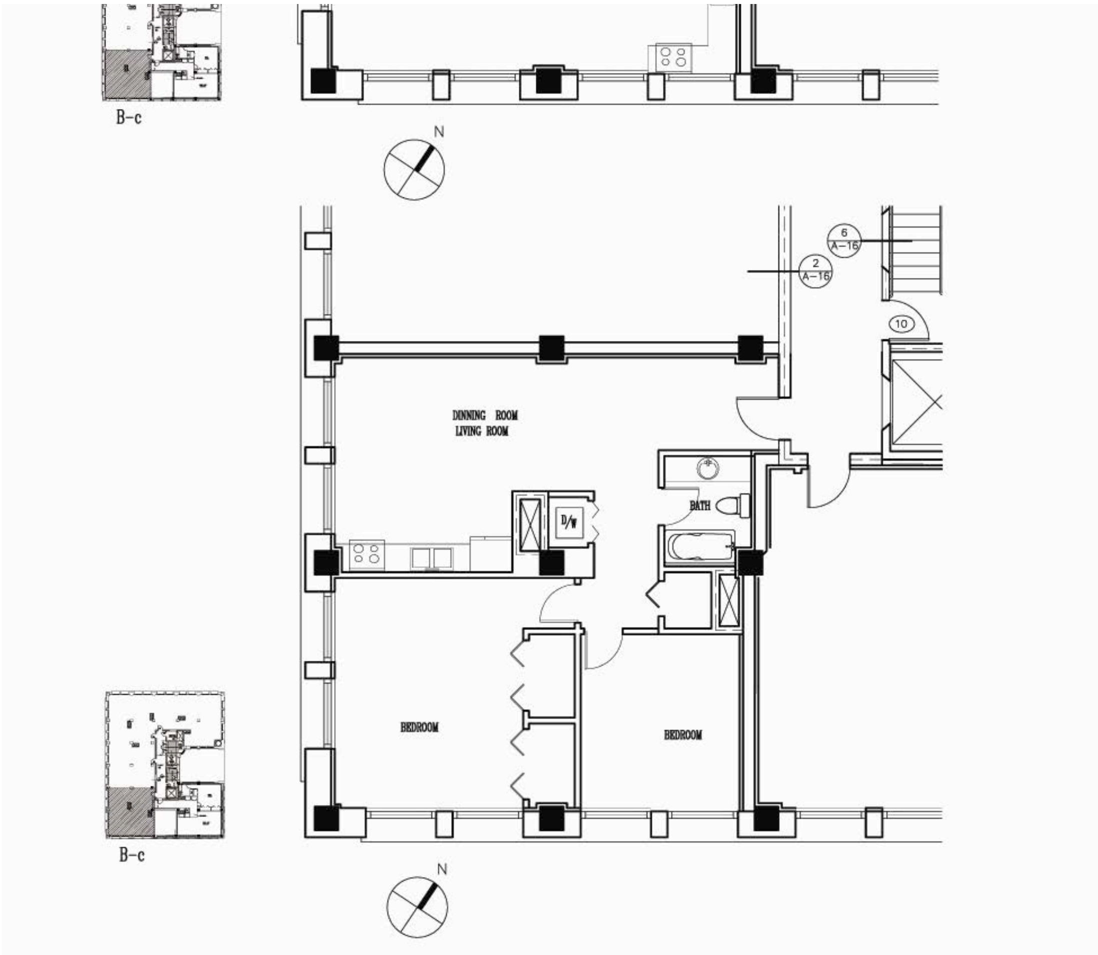

6
A-16
2
A-16
10
DINNING ROOM
LIVING ROOM
D/W
BATH
BEDROOM
BEDROOM
B-c
N


B-a
N

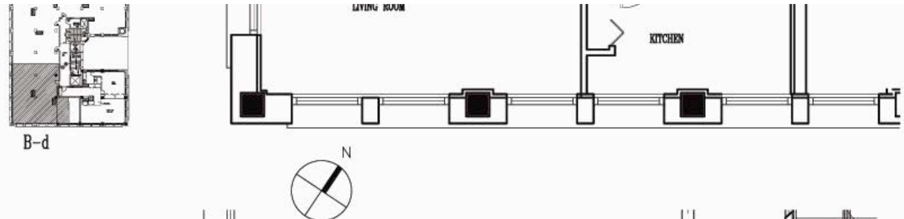

10
BEDROOM
BATH
D/W
KITCHEN
BATH
DINNING ROOM
LIVING ROOM
KITCHEN
B-b
N

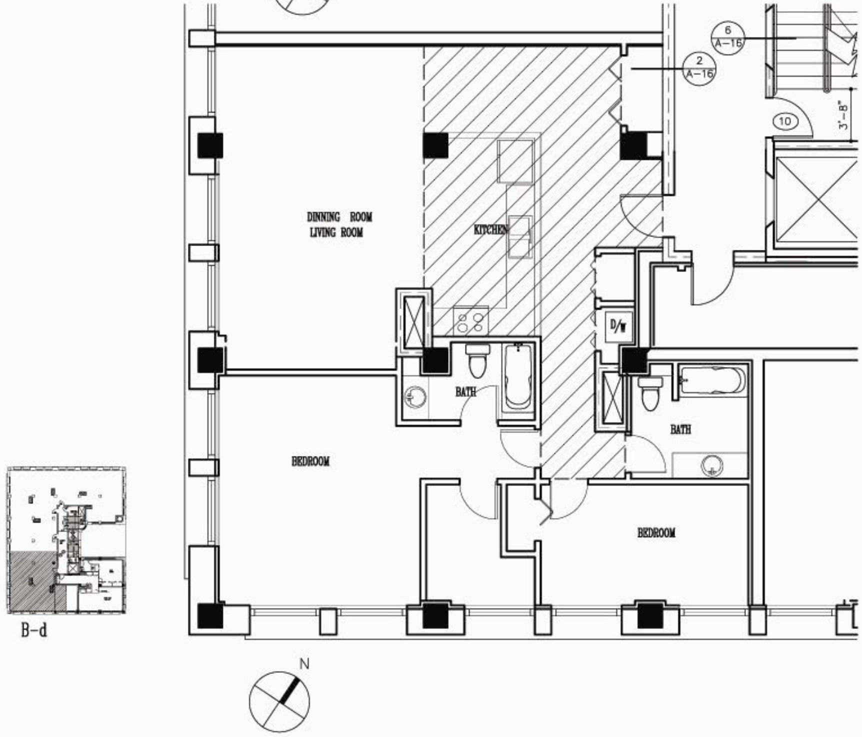

B-a
N

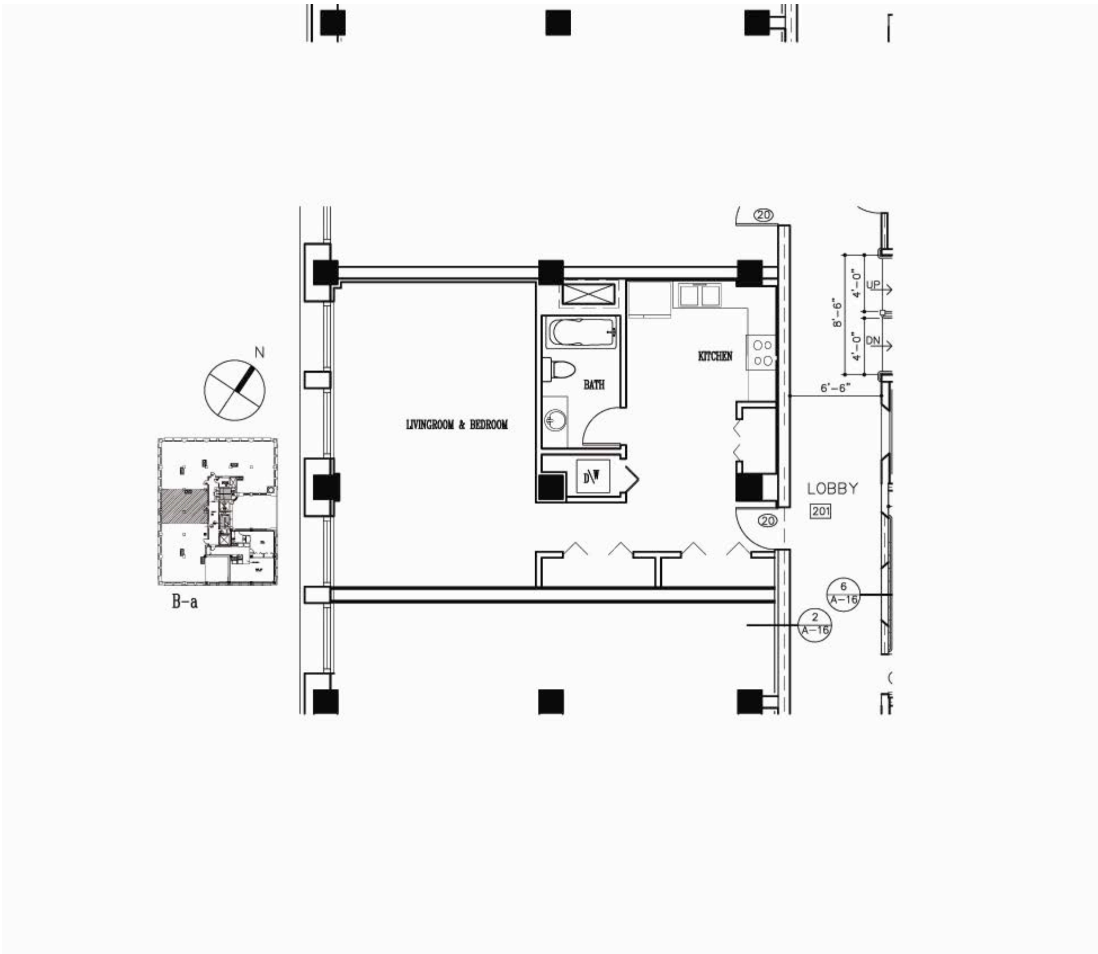

10
3'-8"
BATH
D/W
LIVING ROOM
KITCHEN
DINNING ROOM
BEDROOM
BEDROOM
B-a
N

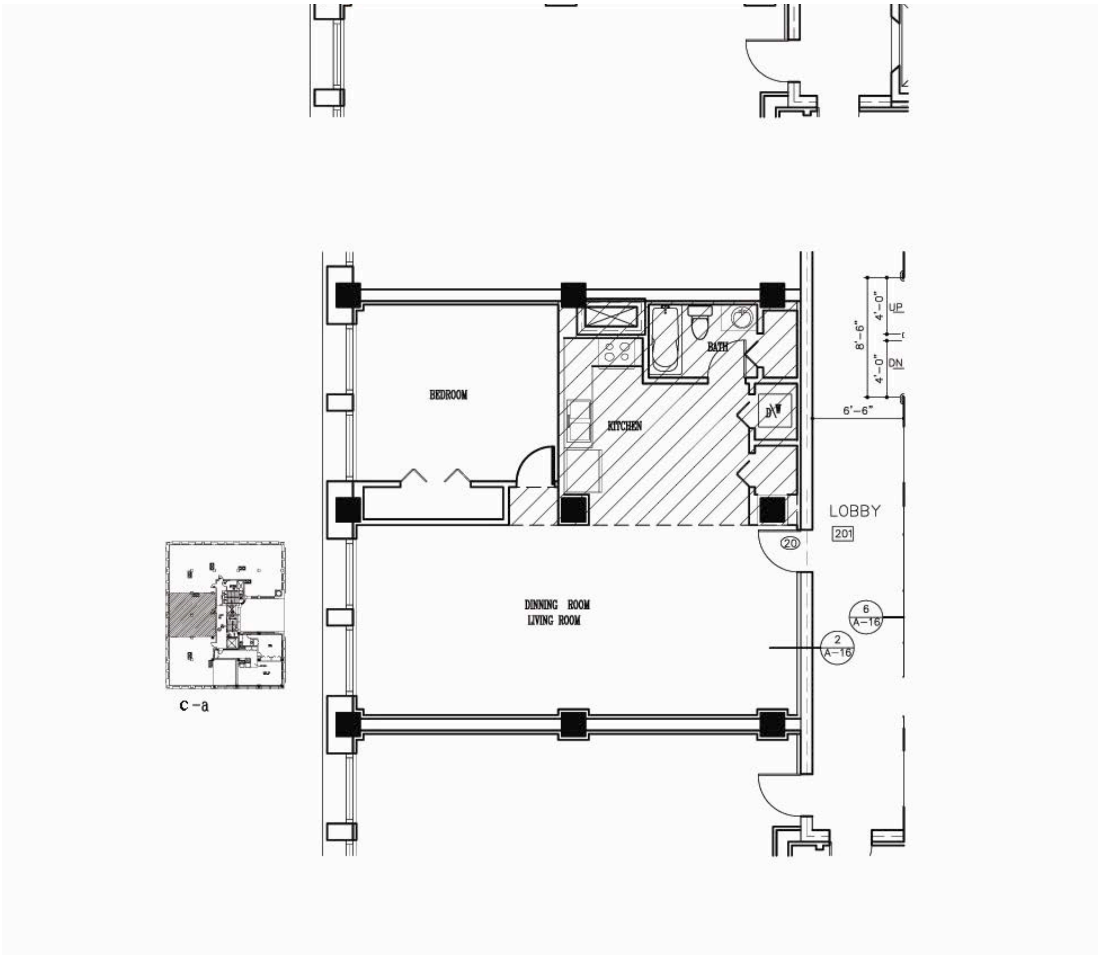


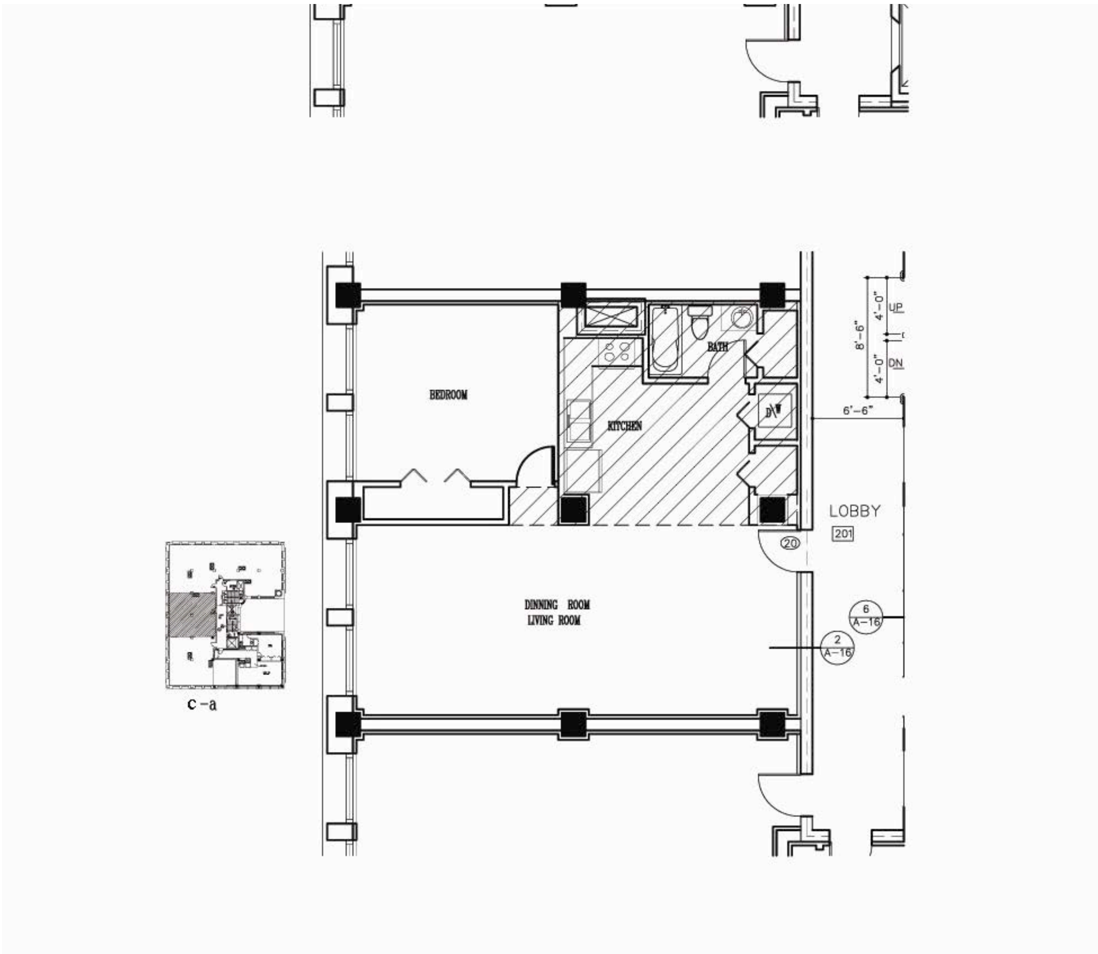
B-c
N
6
A-16
2
A-16
10
DINNING ROOM
LIVING ROOM
BATH
D/W
BEDROOM
BEDROOM
B-c
N

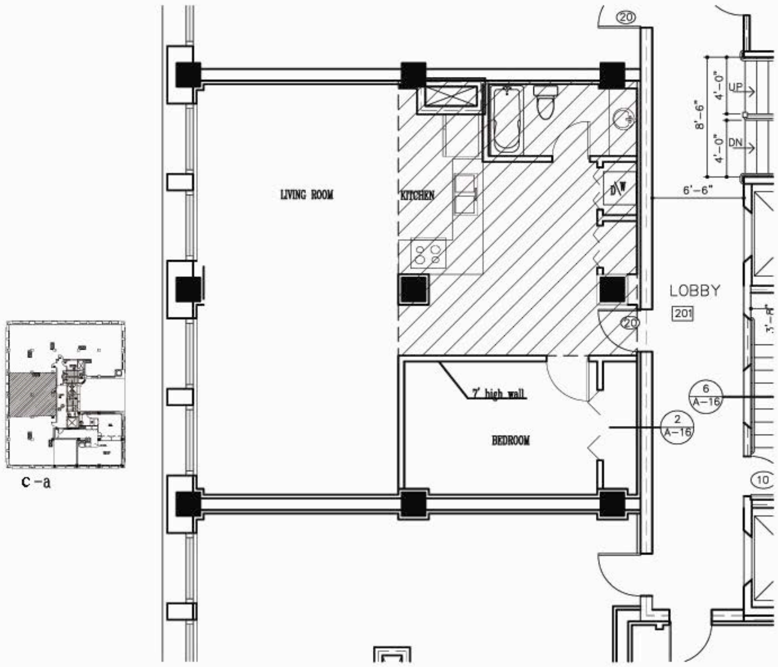

LIVING ROOM
KITCHEN
B-d
N


6
A-16
2
A-16
10
3'-8"
DINNING ROOM
LIVING ROOM
KITCHEN
D/W
BATH
BATH
BEDROOM
BEDROOM
B-d
N

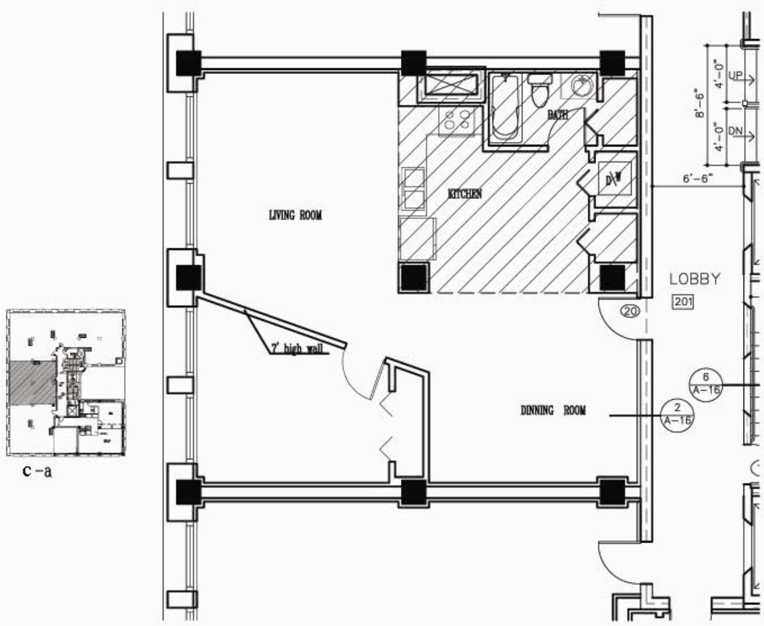

N
B-a
LIVINGROOM & BEDROOM
BATH
KITCHEN
D/W
LOBBY
201
8'-6"
4'-0"
4'-0"
UP
DN
6'-6"
20
20
6
A-16
2
A-16


BEDROOM
KITCHEN
BATH
DINNING ROOM
LIVING ROOM
LOBBY
201
20
6
A-16
2
A-16
8'-6"
4'-0"
UP
4'-0"
DN
6'-6"
c-a


BEDROOM
KITCHEN
BATH
LOBBY
201
DINNING ROOM
LIVING ROOM
8'-6"
4'-0"
4'-0"
UP
DN
6'-6"
20
6
A-16
2
A-16
C-a



LIVING ROOM
KITCHEN
BEDROOM
7' high wall
LOBBY
201
8'-6"
4'-0"
4'-0"
UP
DN
6'-6"
D/W
6
A-16
2
A-16
20
20
10
c -a



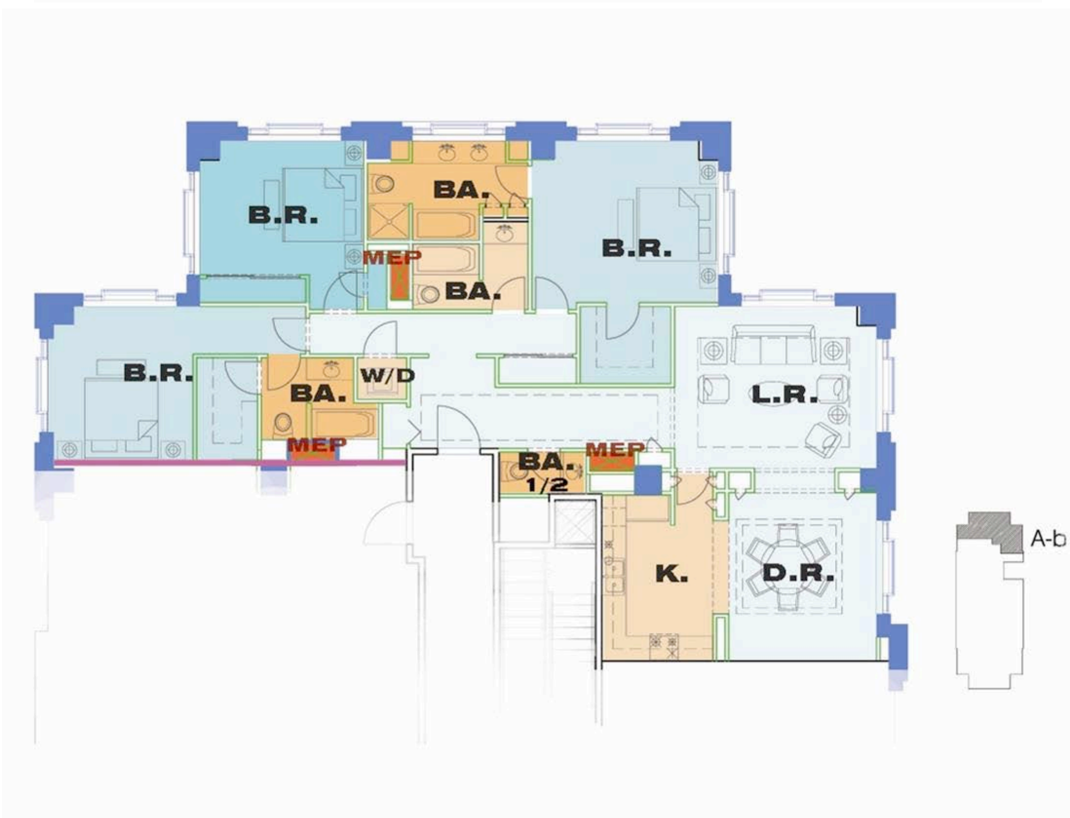
LIVING ROOM
KITCHEN
BATH
DINNING ROOM
7' high wall
LOBBY
201
8'-6"
4'-0"
4'-0"
UP
DN
6'-6"
D/W
6
A-16
2
A-16
20
c -a

Append

MEP
K.
L.R.
B.R.
BA.
W/D
MEP
BA.
B.R.
A-b

BA.
B.R.
MEP
BA.
B.R.
L.R.
W/D
MEP
K.
D.R.
A-b

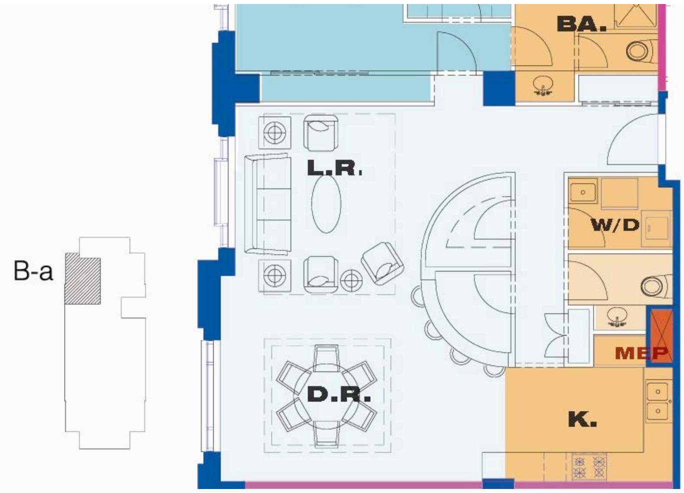
D.R.
K.
MEP
B.R.
BA.
1/2
W/D
L.R.
B.R.
MEP
MEP
BA.
B.R.
BA.
A-b



BA.
B.R.
B.R.
MEP
BA.
B.R.
W/D
BA.
L.R.
MEP
BA.
1/2
MEP
K.
D.R.
A-b

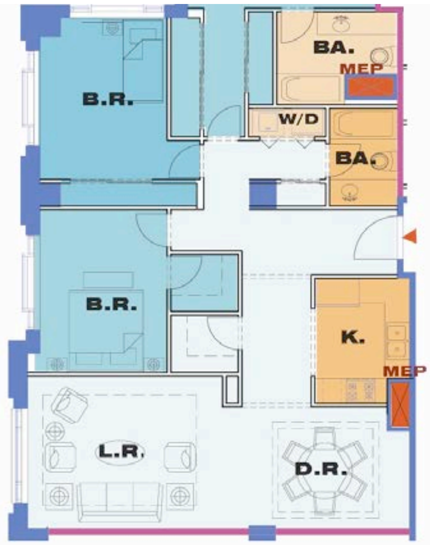

K.
D.R.
L.R.
MEP
B.R.
BA.
MEP
BA.
W/D
MEP
BA.
B.R.
A-b


K.
D.R.
L.R.
MEP
B.R.
BA.
MEP
BA.
W/D
MEP
B.R.
B.R.
BA.
A-b


B-a
BA.
L.R.
W/D
MEP
D.R.
K.

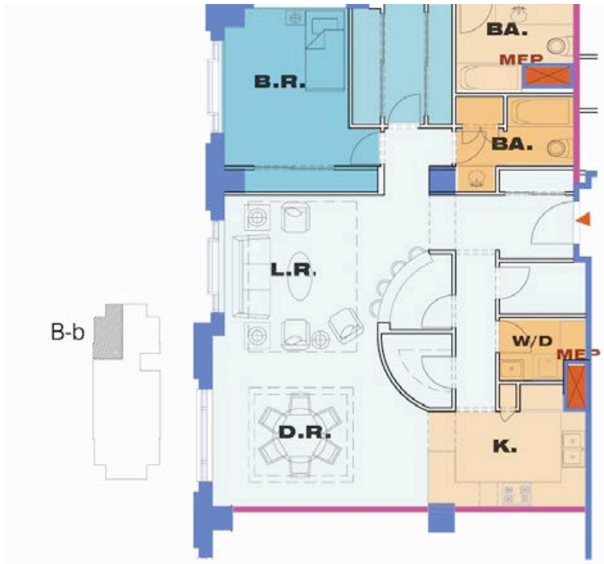

B-a
MEP
D.R.
K.
L.R.
BA.
1/2
W/D
MEP
B.R.
BA.

B-b



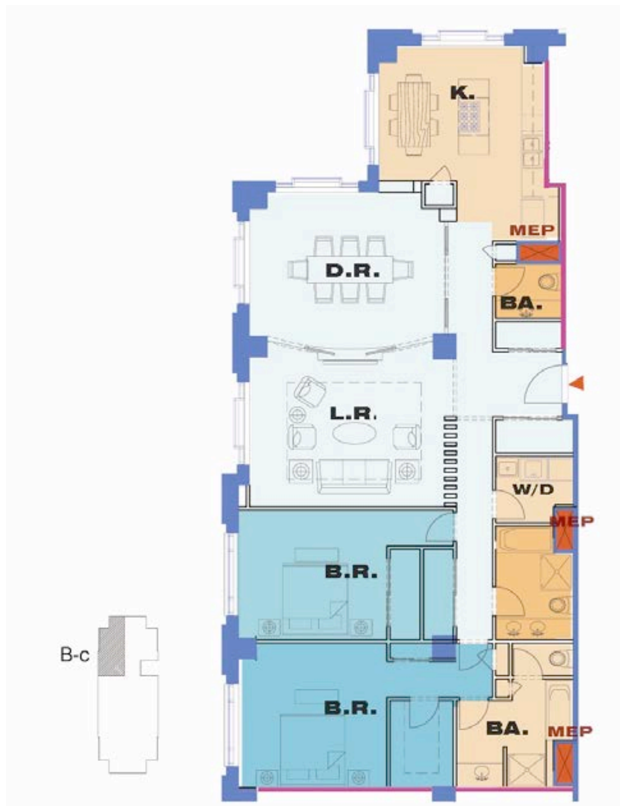
B-b

B-b



B-c


L.R.
MEP
B.R.
W/D
MEP
B.R.
BA.
B-c
B.R.
BA.


K.
MEP
D.R.
BA.
L.R.
W/D
MEP
B.R.
B-c
B.R.
BA.
MEP


BA.
1/2
MEP
L.R.
B.R.
W/D
BA.
MEP
B.R.
BA.
B-c


MEP
BA.
B.R.
K.
MEP
D.R.
W/D
L.R.
BA.
1/2
MEP
BA.
B.R.
B-c


MEP
BA.
B.R.
BA.
MEP
W/D
B.R.
L.R.
BA.
1/2
MEP
K.
D.R.
B-c

Bibliography

2003 Uniform Plumbing Code - IAPMO/ANSI UPC 1-2003. International Association of Plumbing and Mechanical Officials. 2002, Walnut, CA.

Brand, Stewart, *How Buildings Learn - What Happens After They're Built*. Viking, New York, 1994.

Building Futures Institute. 2002. Website report on the INO Hospital. www.bsu.edu/cap/bfi Research Domains-Open Building Studies-Reports-INO report.

Butt, Thomas. *"The Condo Conundrum"*. The Construction Specifier, May 1993, pp.132-141.

Carp J. C. *Keyenburg A pilotprogect SAR*, Eindhoven . NL. 1985.

Durmisevic, E. & Dorsthorst, B. J.H. *the "Service Life Versus Use Life Cycle: a Way to measure the environmental impact of different transformation scenarios"* Open House International Vol.28 no.2 (2003): 23.

Francis D.K. Ching & Cassandra Adams, *Building Construction Illustrated*, 2nd ed. New York: Van Nostran Reihold, 1991.

Friedman, Avi, *The Grow Home*, New York: McGill-Queen's University Press, 2001.

Friedman, Avi. *Adaptable Housing; Designing Homes for Change.* McGraw Hill, New York: 2002.

Habraken, N. J. et al., translated by W Wiewel, edited by Sue Gibbons, *Variations – The Systematic Design of Supports*, Cambridge, MA: MIT Laboratory of Architecture and Planning, 1976.

Habraken, N. J., & Boekholt et al., *Variations-the systematic Design of Supports*, Cambridge, MA: Awater, 1983.

Habraken, *Shell Infill House*, a housing design project, 1987.

Habraken, N. J., *the Appearance of the Form*, 2nd ed., Cambridge, MA: Awater, 1988.

Habraken, N.J., edited by Jonathan Teicher, *The Structure of the Ordinary*, Cambridge, MA: MIT Press, 1998.

Habraken, N. J., *Supports: An Alternative to Mass Hosing, Mumbai*, UK: The Urban International Press, 1999.

Hatch, Richard C., *The Scope of Social Architecture*, New York: Van Nostrand Reinhold Company, 1984.

Hong Kong Housing Authority, *Public Housing in the New Era – Shui Chuen O Architectural Design Competition*, Hong Kong, China: Hinge Publications, 2001.

Jia, Beisi, *Adaptable Housing Design*, Nanjing, China: Southeast University Press, 1998. (In Chinese)

Jia, Beisi, *Infill Components in Housing of High Urban Density: The Past, the Present and the Future of Hong Kong Housing Sustainable Development*, published on Open Housing International [Periodical], Vol.26, No.3, 2001.

Jones, John Chris, *Design Methods*, 2nd, New York: Van Nostrand Reinhold, 1992.

Kendall, Stephen, Shell/Infill: *A Technical Study of a New Strategy for 2x4 Housebuilding* (A HDP Publication, Massachusetts Institute of Technology, 1986)

Kendall, Stephen, *Building Maintenance & Management*, Number 122, Vol.21.1999 (In Japanese)

Kendall, Stephen & Teicher, Jonathan., Residential *Open Building*, Great Brittain, E & FN Spon, 2000.

Lawrence, Roderick, *Hosing, Dwellings and Homes – Design Theory, Research and Practice,* Great Britain: John Wiley & Sons, 1987.

Lee, Bora & Lee, Hyunsoo., *"Typical Plan Types of Flexible Housing Based on the Analysis of Variation Trends"*, Design Living Urban Structures: International Conference on Open Building, 2003.

Liu, Yi-Wei, *"Atrium Type Collective Housing in SuZhou: Applying Bioclimatic Principles in Open Building Design"* (Master Thesis, Ball State University, 2000.)

Liu, Peng, *"Residential Identity of Individual Homes in High-Rise Residential Towers"* (Master Thesis, Ball State University, 2001.)

Lin, Li-Chu, *"Architecture Construction Theory of Open Interface"* (Ph. D. diss., National Cheng-Kung University, 2002.)

Macsai, John et al., *Housing*, 2nd ed. New York: John Wiley & Sons, 1982.

Open Housing International [Periodical], Vol.20, No.3, 1995.

Open Housing International [Periodical], Vol.26, No.3, 2001.

Open Housing International [Periodical], Vol.28, No.2, 2003.

Rombouts, Christine, *"Historic Reuse"*, Urban Land, October, 2003: 65

Tiuri, Ulpu and Tarpio, Jyrki, *Infill Systems for Residential Open Building: Comparison and Status Report of Developments in Four Countries.* Helsinki University of Technology, Helsinki, Finland. 2001.

Turner, John F. G., *Housing by People – Towards Autonomy in Building Environments*, New York: Pantheon Books, 1977.

Yonkin, Dale, *"Converting Commercial Space to Residential"*, Urban Land, January 2003: 59