Spatial Properties of Frank Lloyd Wright's Prairie Style: A Topological Analysis

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Statement of Originality

The thesis contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. I give consent to the final version of my thesis being made available worldwide when deposited in the University's Digital Repository subject to the provisions of the Copyright Act 1968.

Signature:

Peiman Amini Behbahani

To my father

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In the following list, only the major recurring abbreviations are listed.

AID	Angular interspatial depth
AMD	Angular mean depth
D-K	Dining room - kitchen (depth)
DxK	Dining room to kitchen (axial line)
DxL	Dining room to living room (axial line)
E-D	Entry - dining room (depth)
E-K	Entry - kitchen (depth)
E-L	Entry - living room (depth)
HIAL	Highly integrated axial line
HIX	Highly integrated intersection
i	integration
I	Prairie house type 1
IA	Isovist area
IA1	First subtype of type I
IA2	Second subtype of type I
IB1	Third subtype of type I
IB2	Fourth subtype of type I
II	Prairie house type 2
IIA	First subtype of type II
IIB	Second subtype of type II
k	The number of nodes in a graph, or of cells in a grid. If used with a subscript (e.g. k_r), indicates the number of nodes or grid cells in space *r*.
L-D	Living room – dining room (depth)
L-K	Living room - kitchen (depth)
p	(usually as *p*-value) the probability of randomness or null hypothesis, as the indicator of statistical significance.
SID	Step interspatial depth
SMD	Step mean depth
SxL	Service zone to living room (axial line)

Abstract

Frank Lloyd Wright's Prairie houses have been repeatedly praised for introducing a number of innovations in domestic spatial planning. In particular, historians and critics have identified several properties as signalling a departure from the formal characteristics of Victorian architecture of the United States. However, despite these claims, the actual spatial properties of the Prairie houses, whether in comparison to the Victorian houses or to themselves, have never been quantified. A quantitative analysis would enhance the objective understanding of this style. Hence, this thesis presents the results of a two-stage computational analysis of Prairie houses using space syntax techniques. The thesis analyses the floor plans of twenty-seven Prairie houses and fifteen Victorian houses. In the first stage of the research, the Victorian and Prairie houses are compared in order to investigate the claims in the literature as well as to identify any overlooked similarities or differences between the two design trends. In the second stage of research, only the Prairie houses are analysed in order to understand the differences and similarities between them, especially in regard to their diverse layout characteristics.

The results of the first stage suggest that, within the limits of the methods used, the Prairie houses were not so inventive as claimed in previous studies. Nevertheless, the thesis also identified possibilities for alternative interpretations of the results that might begin to explain this accepted position. In addition, the results of the first stage identified a number of previously unknown features (such as genotypes) in both Victorian and Prairie houses. The results of the second stage showed that the Prairie houses are significantly diverse in regard to their spatial properties. The thesis also found that there is a limited relationship between some of the measured layout features of the measured spatial properties.

1. Introduction

1.1. Research problem and solution

This doctoral dissertation is inspired by the idea that the understanding of the early twentieth-century Prairie style movement in architecture will be improved by using a quantitative approach to analyse this period of design. In this regard, the present thesis addresses one aspect of Prairie style houses, that being the topological features of their interiors.

The Prairie style is one the most acknowledged and influential housing styles of the early modern movement, and arguably influenced later design trends especially in the United States (Giedion, 1962; Brooks, 2006). Along with its parent style, the Chicago school, it redefined architecture in the U.S. from its nineteenth-century milieu into the twentieth century, especially under the genius of one of its most famous proponents, Frank Lloyd Wright (Brooks, 2006).

The Prairie style is admired for a large range of characteristics including its form, usage of materials, and spatial arrangements. These characteristics were initially presented by Wright (1960) as innovative or revolutionary and these views have been reiterated by more contemporary scholars and critics (Charles, 1908, quoted in Chan 1992; Giedion, 1962; Benevolo, 1971; Curtis, 1996).

The architectural characteristics of the Prairie style have been the subject of various studies since its formative years. Most of these studies, especially those before the 1980s, were based on qualitative methods and in some cases, on the subjective inference derived from the visual observation of the design or its documentation (e.g., Twombly, 1979; Maddex, 2000, 2002). While many of the characteristics of the Prairie Style may be directly observable in this way, due to their visual nature (e.g., forms, materials, and motifs), some others, such as *topological* properties, have more indirect and complex aspects (hereafter, the term 'topology' and its derivatives are used only for the relationships between the the void of spaces devoid of physical form). For example, the Prairie houses are considered more holistic and integrated spatially (Wright, 1960; Twombly, 1979) or they facilitate more interaction between family members (Maddex, 2000) (for a more in-depth analysis, see Chapter 2). None of these have been developed by a method specific to topological features.

Conversely, since the 1980s (though the concept originated in 1960s and 70s) numerous quantitative methodologies and techniques have been developed by researchers to objectively measure various topological features of architectural space. In particular, space syntax theory (Hillier & Hanson, 1984) provides an extensive set of techniques for quantifying the topology of space. Space syntax techniques have already been used or proposed to investigate qualitative properties of buildings (Hanson, 1999; Franz & Wiener, 2008; Dawes & Ostwald, 2014a).

The present research focuses on the analysis of Prairie style houses using space syntax techniques. Although the findings of existing literature are examined in this research, their investigation or possible revision is not the main factor leading to the definition of the research problem. The main motivation for this thesis originates from a desire to construct a quantitative picture of this important architectural style, especially in regard to its critical position in the history of house design.

The main problem is that the studies in spatial features of Prairie houses are mainly confined to qualitative methodologies, some of which may be fairly subjective as they were originally made by the founder of the style. Even the studies which had a quantitative approach only focused on a few distinguished houses in a larger context (e.g. other works by Wright). A number of the identified spatial features were explicitly or implicitly derived from a comparison with the preceding Victorian houses. In addition, many of the studies focus entirely on form, largely ignoring its reciprocal, space.

To resolve this issue, a quantitative analysis of the topological features of Prairie houses is necessary. This research uses space syntax methods and techniques – as one of the most comprehensive approaches to spatial analysis – to conduct measurements of, and then analyse, both Prairie houses and the dominant architecture in the Victorian era, the time that led to the creation of the Prairie style. Given the acknowledged individualism of the Prairie houses (Wright, 1960; Chan, 1992), the analysis then extends to a comparison *between* Prairie houses.

1.2. Goal and objectives

The main goal of the present research is to develop a rich topological understanding of Prairie style houses *per se* as an architectural style, and in context, as a revolutionary historical style. In regard to this goal, there are three objectives.

The first objective is to provide an alternative understanding of the topological features of the Prairie houses. This includes finding how a user (whether a dweller or visitor to the houses) would have perceived the relationships between the spaces in the house, and how the whole house might have been mapped by a person inside it. Note, that in the use of space syntax methods in this thesis, the findings on interaction between users and space will be restricted to an abstracted image of the space based on visibility and access.

The second objective is to identify the differences and similarities between the Prairie houses and their late Victorian-era (before 1901) predecessors. One aspect of this objective pertains to investigating the existing findings and claims about the innovations found in the Prairie houses. In this regard, a goal of this research is to re-examine these claims using the techniques of space syntax theory. Another aspect of this objective is to capture further topological similarities and differences between Prairie houses and late-nineteenth century houses.

The third objective is to understand the reason for the existence of the identified topological features in Prairie houses. Regarding the geometrical premises of space syntax, the focused "reasons" in this research are encompassed in the relationships between layouts and topological features of the houses. Hence, this objective can be rephrased as understanding the correlation between the design of the layout of each house and of its topological properties.

1.3. Research design and methodology

Considering the objectives of the research, there are two distinct focuses to the dissertation: the first, comparing American Prairie and Victorian houses, and the second, the Prairie houses themselves. This leads to two stages of research:

- Stage I: the first stage contains a comparison between Prairie and Victorian houses. This stage includes a comparative case study using houses designed by a range of architects (shortly before Wright began his independent career in 1893) as representatives of the American, Victorian-era house design, and houses designed by Wright after the Prairie principles were established (in late 1890s). For the sake of comparability, the houses were limited to smaller scale suburban houses with a relatively simple "functional" programmes. The case study was carried out by applying a number of space syntax techniques to both sets of cases, and the results of their measurements were compared and analysed. A significant portion of the results of this stage, as well as the relevant literature review and methodology, is reported as a paper (Amini Behbahani, Ostwald and Gu, 2016) in *The Journal of Architecture*.

- Stage II: the second stage of the research addresses the third objective. In this stage, the topological properties of Prairie houses are compared with their *formal* features (shape, layouts, and other elements) which are identified in the literature. The basis of the analysis is a statistical correlation between the topological and formal features of the houses.

The combined findings of these two stages contribute to achieving the first objective of the research – developing a new quantitative understanding of the Prairie houses.

For most of the analysis in this research, *depthMapX* (Varoudis, 2014) is used as the main analysis software. However, two other tools (*Viraph* and *DAG*) developed by the author are also used for measures which depthMapX does not provide (these tools are described in 4.5.2, 4.5.3 and Appendix III).

1.4. Outcomes and Contributions

The outcomes and contributions of this research are categorised in two regards. First, some of the outcomes are *topical*, in that they are directly related to the topic of this thesis (Prairie houses), while other outcomes are *lateral*, pertaining to the related fields or areas. Secondly, outcomes and possible contributions may relate to different areas of design research, such as design history and design computation. In this regard, there are two outcomes related to design history:

- The main outcome of this research pertains to the history of architecture. This research provides a new understanding of Prairie style houses. The findings of this research both complement and question the existing literature on the Prairie style, and support a new understanding both of the style and its main creator, Frank Lloyd Wright.

- The second outcome is an understanding of the topological features of late-Victorian houses in the USA, which, to the author's knowledge, have not been addressed previously in any literature. Nevertheless, this outcome is not as thorough as that of the Prairie houses, although it will form a solid basis for future studies.

Other outcomes of the research pertain to design computation (analysis), based on the methods used for analysis.

- The relationship between form and semantics has been an important focus of design research and behavioural science for a long time. A particular aspect of this relationship is between shapes (e.g., shape grammar) and topology (space syntax). This relationship (and other similar relationships) was previously approached by a number of researchers such as Eloy (2012), Lee, Gu and Ostwald (2013), and Lee, Ostwald and Gu (2015) who sought to combine design grammar and space syntax methods. The second stage of the present research (i.e., the third objective) attempts to define a basic relationship between layout and topology which can be later used for such combinatory approaches. In this regard, the outcomes may assist future researchers to more easily determine what layout features may be more influential in different topological properties.
- While this research uses techniques and methods which have been previously applied in numerous publications on space syntax, there are a few modifications and proposed techniques for measuring some of the topological properties. While these innovations or modifications are not yet fully reviewed, and their usefulness may be questioned, they contribute to the extension of the existing space syntax framework.
- Part of this thesis investigates several existing claims made by architectural historians. A contribution of this thesis would be an insight into the (degree of) usefulness of space syntax techniques for investigating historical claims, and how much the understanding of a

historic space of culture can be examined using these techniques. Nevertheless, it should be noted that Prairie houses are still a relatively recent development in the larger history of the built environment.

1.5. Scope and limitations

As mentioned, the focus of the research is on houses with relatively simple plans, which therefore comprise only a fraction of Victorian and Prairie houses of this era and geographic location. This limits the selected cases from being complete representatives of each style. Another limitation pertains to the definition of "Prairie" house. Although the term "Prairie style" is used throughout this research, only the houses designed by Frank Lloyd Wright were selected as Prairie cases. More importantly, this research defines Prairie style more as a *period* (during Wright's residence in Oak Park, 1893-1913) than a *style* in a strict sense. In this regard, the research is largely concerned with the houses Wright designed in his Oak Park studio.

These limitations to case selection impose their own statistical limitations because of the sample size. While different statistical functions were applied to increase the validity of the analysis, the small sample size may reduce the degree of certainty towards correlations (or lack of them) found in the analysis.

A final limitation relates to space syntax theory. This theory reduces architecture to the pure geometry of permanent boundaries. Therefore, both the analysis and results of this research are limited to this aspect of design. In addition, the space syntax techniques are applied only on the floor plans of the houses not their section or perspectives.

1.6. The structure of the thesis

This thesis is structured into eight chapters and four appendices. This introduction (Chapter 1) is followed by two literature review chapters, the research design, four chapters of analysis and results, a conclusion chapter, and the appendices:

- Chapter 2 discusses the characteristics of the Prairie style houses that are the subject of this research. This chapter includes an explanation of the context (socio-economic and architectural) of the evolution of the Prairie style out of the architecture of the Victorian era of the United States. The chapter concludes with enumerating features of layout and space in the Prairie houses as discussed in the literature.
- Chapter 3 reviews space syntax, its applications, limitations, and techniques – both in general and specifically regarding the theme of this thesis. In this chapter, the basis for the calculations used for the analysis is also explained.
- Chapter 4 outlines the research design and methodology. The chapter discusses two stages of the research which include two case studies respectively. The first stage compares Prairie houses with their Victorian predecessors, while the second stage compares the Prairie houses to each other. This chapter also discusses the computational methods and tools of measurements as well as the hypotheses testing and statistics used for analysing the results.
- Chapters 5 to 8 contain the results of the case studies and their analysis. Chapter 5 includes the first stage of the research (the comparison between Prairie and Victorian houses) which outlines the differences and similarities between the two stylistic approaches. Chapters 6, 7 and 8 contain the results and analysis of three respective technical approaches of space syntax (namely, *convex, isovist,* and *axial mapping*, see Chapter 2) on the Prairie houses. These three chapters

include the main case study and results regarding the objectives of this research.

- Chapter 9 (conclusion) summarises the overall results and findings of the previous four chapters. This chapter also discusses possible future directions for research.

There are also four appendices in this thesis, mainly providing the raw material and results:

- Appendix I illustrates the floor plans of the Victorian and Prairie houses analysed in this thesis.
- Appendix II includes the detailed numerical results for all cases.
- Appendix III presents the features of the two computational tools developed by the author for this thesis.
- Appendix IV briefly discusses the related publications produced during this PhD research.

2. Prairie houses

2.1. Introduction

The Prairie style is a collective term for a trend – or school of design – in the early twentieth century in the mid-western United States (Brooks, 2006). Although there are a considerable number of different types of buildings that have been completed in the Prairie style, the style is mainly attributed to a vast number of single family houses (Chan, 1992). The name "Prairie" itself is derived from the geographical context of the houses – the prairies of the mid-western United States – although the name was widely accepted only decades after the heyday of the style (Brooks, 2006).

Prairie style is often described in dramatic terms as "breaking" (Curtis, 1996) from the past or signalling a "revolution" (Summerson, 1970) against the architecture of the nineteenth century. Understandably, the literature, both contemporary and more recent, typically devotes a large portion of its claims to a consideration of the revolutionary innovations of the Prairie style compared to prior design styles. These innovative features range from social values and lifestyle of the designers and clients to the form and spatial details of the houses. On the other hand, scholars such as Scully (cited in Laseau & Tice, 1992, p. 15) have described some of Wright's claims of innovation as exaggerations and as a refusal by him to acknowledge other influences. Nevertheless, to understand the Prairie style it is necessary to study its social, economic, and technological background and their reflection in architectural design.

A significant number of studies construct such a comparative narrative addressing three questions – why the previous architecture had not been appropriate (in the eyes of Wright, and sometimes the author of the narrative), what should have been appropriate, and how the more appropriate response of the Prairie school was realised into design? In such an approach, there is usually a great emphasis placed on the opinions and statements of Wright and other contemporary architects of the era. However, another approach to studying the Prairie houses does not (explicitly) compare them with prior design, but instead tries to identify and analyse inherent properties of the Prairie style. The latter studies are generally more recent and in some cases more focused on certain topics. It should be noted that relatively few studies restrict their analysis of the Prairie style to just one of other of the approaches. In most cases, both approaches are combined, even if one may be more focused according to the topic of the study.

The structure of this chapter parallels the comparative approaches found in the literature. Hence, it begins with a discussion of the socio-cultural values of the second half of the nineteenth century (Victorian era) in the United States, how these values were represented by the residential architecture of that era, and how they were criticised and countered near the end of that era. The next section (2.3) explains the general characteristics of the Prairie style with regard to forms, layouts, elements, spatial programme and features. This section is followed by a summary of more detailed studies which explain the form and topology of Prairie houses. The final two sections (2.5 and 2.6) summarise the results of these past studies and try to identify issues and gaps in the literature.

2.2. From the Victorian to Prairie houses

The Victorian era refers to the years of Queen Victoria's reign from 1837 to 1901. This era was shaped by a number of revolutionary events such as the industrial revolution and rapid urbanisation. Such events had a profound impact on both the economy and culture of the American people and the way they shaped and defined their living spaces. It was at the end of the Victorian era that the Prairie style emerged (1900). As such, it is reasonable to assume that the Prairie style was an evolution or reaction to (or both) the architecture of the Victorian era. In this regard, it is necessary to study the context and architecture of the Victorian period in the United States and its relation with, and transition into, the 1900s and the Prairie style of architecture.

In this section, a number of socio-economic features of the Victorian era in the United States, the architectural reflection of those features, and their changes in the 1900s are discussed.

2.2.1. Socio-economic features of Victorian era

The Victorian era commenced in 1837 and ended, with the death of Queen Victoria, in 1901. The socio-economic characteristics of this era had several facets. In this section, only a few are discussed which appear to have been more influential on the domestic architecture of the Victorian era. In American history, the era is viewed as beginning during a period of industrialisation that led to rapid urbanisation and the appearance of a growing urban and middle-class population (Giedion, 1962). In economic terms, the new urban middle class had several opportunities available to them which the urban lower class and rural community both lacked. The middle class had sufficient wealth that it no longer had to rely on women working (Kleinberg, 1999), and men became the sole source of income (Volz, 1992). The middle-class working man left home early in the morning for his workplace in the city centre – for him, work no longer took place in the home (Volz, 1992). The segregation of spaces for work and living was represented for the middle class by a new concept known as *domesticity*. The idea of domesticity was founded in the dichotomy between private (interior) and public (exterior) lives (Grier, 1992).

The appeal of segregation was not necessarily a Victorian invention but a continuation of a shift of values apparently beginning after the Renaissance era in Europe (Evans, 1997, p. 64). Among the newly emerged values was to achieve a sense of privacy through the segregation or reduction of contact by architectural means (Evans, 1997, p. 71). In this regard, a parallel segregation of gender also occurred so that the domestic house became the woman's territory. The home became the centre of comfort and joy for the family, the providing of which was the expectation of a "true woman" (Kleinberg, 1999) who was now the manager of the house. The house was considered a place which shaped the character of its inhabitants, especially any children (Volz, 1992).

Another influence of industrialisation was the mass production, effectively reducing the cost of many other commodities and products which had previously been considered luxuries belonging only to the wealthy upper class (Grier, 1992). As a result, the middle class found themselves being able to imitate the upper class by collecting industrially-produced replicas of fashionable furniture, objects, and designs. The lifestyles and possessions of the wealthy appealed to the *nouveau riche* middle class, for whom luxury was regarded as a sign of civilisation, praised as the "aesthetics of refinement" which implied a direct correlation between the extent of elaborate details and the degree of civilised-ness or *gentility* (Logan, 2001; Grier, 1992).

By the middle of the Victorian era (circa 1870), while gender segregation continued, several of these social values and features were challenged and rejected. While the moral centricity of the home remained unchallenged, the social conventions and practices were increasingly the subject of criticism (Grier, 1992). A crucial challenge to the *nouveau riche* came in the guise of a new taste for simplicity (instead of luxury). Simplicity, for both economic and religious (mainly Puritan) reasons, was gradually represented at the time as a core American value, in contrast to gentility and the other "imported" mores of the European aristocracy (Maddex, 2000). As society's taste changed, simplicity became a virtue for both the design of a home and for the moral education of late Victorian society (McMurry, 1985).

In parallel with these social changes, the growth of urban development was countered by an anti-urban movement in response to the crowded, dirty, and racially diverse conditions of the city (Cromley, 1996; Evans, 1997;

Hoganson, 2002), further endorsing the desire for segregation in more conservative sections. The anti-urbanist agenda had two consequences. First, it encouraged people to live outside the city centre, but still close enough to commute to work. This led to the increasing popularity of suburban communities which became even more popular when the automobile became affordable (Giedion, 1962). The second consequence was the perception of the house, or home, as a refuge from the morally decadent city (Evans, 1997; Kleinberg, 1999). The house became the place where people could define themselves in opposition to the anonymous urban crowd (Volz, 1992).

The Victorian era in the United States signalled the birth and growth of the urban middle class and a culture and economy shaped by industrialisation and mass production, which led to both the growth of cities and affordability of formerly luxury products and services. The design of houses was particularly affected by economic shifts in the Victorian era, when women were expected to stay home and manage the house and lifestyle rather than contributing directly to family's income. The new Victorian home was expected to be a reflection of a family's moral and social values.

The next section discusses the architectural properties of the Victorian houses of this era.

2.2.2. Residential Architecture of Victorian Middle Class

One of the key features of the Victorian house that demonstrates the socio-economic imperatives and values of the era is its spatial organisation. The Victorian house was generally conceived as being made up of a collection of specific, single purpose, interior spaces (Cromley, 1996) which in part, reflects the desire for segregation (of functions, in this case) (Evans, 1997). These spaces could be understood as belonging to one of the three main functional zones of the house; private, service (or utility), and social (or living) spaces (Grier, 1992). The private zone contained rooms dedicated to more intimate family functions such as eating and sleeping. The service zone included the rooms designated for household works and servants. Finally, the social zone was used for reception of the guests and the more social aspects of family life. A reason for the clear planning separation between the social and service zones was because the service zone accommodated the dirty and messy household activities of the house, while the social zone – associated with gentility – was to be more presentable and luxurious (Cromley, 1996). Thus, architects of the era set out to hide the service zone by both reducing its connections to other parts of the house and by positioning it at the rear (Grier, 1992; McMurry, 1985).

To achieve the separation between functional groups of spaces, Victorian plans often featured buffer zones. For example, the dining room was a luxurious space in which only servable food entered. It was also a showplace for the silverware, china, and other food-related luxuries. Between the dining room (social zone) and the kitchen (service zone), architects sometimes placed the butler's pantry, an intermediate part of the service zone where food prepared in the kitchen was reordered prior to being served in the dining room (Cromley, 1996). The butler's pantry was also the place where long-life, neutrally-scented food and drinks were kept. In this regard, pantries served as much to control and regulate the flow of food traffic as to store comestibles.

The dining room and the butler's pantry, along with the kitchen, comprised the "food axis" of the plan (Cromley, 1996). The food axis included the rooms for preparation, storage, and serving of the food. The kitchen was the main space for preparation, the pantry was for both storage and preparation, and the dining room and extensions (including the breakfast room) were for serving and consuming food.

The core space of the early Victorian social zone was the parlour (Logan, 2001). The Victorian parlour was a combination of the Georgian (prior to 1840) "parlour" and the eighteenth-century "drawing room" of upper-class society (Grier, 1992). The parlour was a room for the formal and social activities of the family, ranging from parties to ceremonies such as funerals or weddings (McMurry, 1985). It also served a surrogate role, by exhibiting any "luxury" objects and furniture, collected from around the world. In other terms, it was the main space where the concept of gentility was exposed and realised (Grier, 1992).

Another important space in the Victorian, middle-class home was the library. The inclusion of a library inside the Victorian house was a consequence of the availability of print materials in the age of mass production (Volz, 1992). The library was regarded as a masculine space and so it was usually positioned in a plan in a location far from the more female spaces of the service zone (Kleinberg, 1999). Conversely, in European Victorian society the drawing room was often regarded as a female room, but in its North American incarnation it had become merged into the parlour in most cases (Volz, 1992).

The ground floor spaces of the late Victorian house were usually dominated by a composition of four main spaces: the dining room, kitchen, parlour, and library (Pinnell, 2005). The library was sometimes replaced by a hall, although in many houses both of these room types were present. Because the four main spaces of the ground floor were usually square or thickly-proportioned rectangular rooms which were placed side by side, these houses were colloquially given the nickname "foursquare" (Pinnell, 2005). The outline of the house itself was usually rectangular, close to a square. In some houses a portion of main spaces or a small space might have projected out of the rectangular outline. In the case of main spaces, the projected portion was usually designed as a bay window.

During the last two decades of the Victorian era, several of the established room types began to change. For example, as puritanical and functional tendencies of the middle-class grew, the parlour was increasingly considered an economic and spatial extravagance, a remnant of old-fashioned lifestyle (McMurry, 1985; Grier, 1992). This change placed more emphasis on the intra-family relationship than on social interaction with outsiders and the parlour was reinvented as a “living room” (Grier, 1992) or “sitting room”, recalling the name used in historic rural houses (McMurry, 1985). Another change which contributed to the demise of the parlour was the transference of a number of formal functions to the exterior of the home (Grier, 1992). For example, funerals and weddings were held in commercial or communal establishments and the existence of public and school libraries reduced the need for them to be held in houses (Kleinberg, 1999).

Nevertheless, Victorian house design in the U.S. was not a singular and consistent architectural style. There were numerous variations, both as a result of the architects’ personal choice (e.g., Henry Richardson and Bruch Price) or a popular trend, usually imported from or parallel to European designs (e.g., Queen Anne style) (Whiffen & Koeper, 1981). In general, American clients of the 1800s adopted various styles including, for example, the elaborately-decorated New Empire style (from Napoleonic France), High Victorian Gothic (from Britain, as influenced by John Ruskin), Colonial Spanish style (from Latin Americas) and Queen Anne style (from Britain) (Whiffen, 1969). The last example was mainly introduced to the United States at the Philadelphia exposition in 1876 through two buildings erected by the British representative. The two buildings were two-storey houses with half-timber structure, stucco plastered walls, steep roofs and a prominent chimney (Whiffen & Koeper, 1981). This style was widely admired by American architects and was soon adopted as the latest trend in architecture. While façade and materials were an important part of the attraction of this style, the interior design was also spectacular with its combined hall, fireplace, and stairways (Whiffen & Koeper, 1981).

The Queen Anne style was later (in the 1880s) modified or *Americanised* as the so-called Shingle Style, because it used shingles to cover the exterior walls. In some Shingle houses the position of the fireplace in the hall was emphasised by stretching it and lowering the ceiling above (Whiffen & Koeper, 1981). Another feature of Shingle houses was their “messy” floor plans in the sense they were not symmetrical, and had irregular projections bays and porches around the main rectangular outline of the house. However, there was at least one exception of Bruce Price houses (e.g. Kent house) with symmetrical cruciform layout.

Another exception was the work of architect Henry H. Richardson. He had actually built a Queen Anne style house (Watts Sherman House in 1875) before it was introduced in the Philadelphia Exposition of 1876 (Whiffen, 1969). While considered Romanesque in their exterior appearance, the houses by Richardson feature an intermarriage of French order and symmetry and English asymmetry (Whiffen & Koeper, 1981). This contrast was apparently manifested according to the function of spaces: the symmetric front form of house hosted the social (male) zones while the asymmetric rear hosted the service (female) zone (Frampton, 1992).

Another important style of the middle-to-late Victorian era was later known as the Stick style (for its use of partially exposed wooden structure). The Stick style was almost fully evolved inside the United States (Whiffen, 1969) where it was praised for its exposed wooden construction which was deemed to have a degree of "truthfulness" about it (Whiffen & Koeper, 1981). This, in itself, suggests a shift in ideals in the late Victorian era. It is arguable that similar honest simplicity was found in the Shingle style, compared to its Queen Anne style predecessor, as the newer style limited the use of material of the exterior finishing to mainly shingle and stone from the more colourful texture combination in the Queen Anne style (Whiffen, 1969; Whiffen & Koeper, 1981).

In any case, to a certain extent, the differences between these design trends were mainly associated with the appearance of buildings including façade proportions, emphasised lines, ornaments, particular local materials, and so on. Meaningful differences in spatial organisations were limited to exceptions such as those found in the work of Richardson. While "simplified" styles, such as Shingle or Stick houses, became popular in the late 1800s, the neo-Classic and Gothic styles, often featuring a high level of eclecticism, were also popular and continued to be built well into the twentieth century (Whiffen & Koeper, 1981).

Overall, the Victorian house was designed to reflect and accommodate the lifestyles and values of its society. However, it was not necessarily a fixed or finite architectural type, as throughout the era the Victorian house was increasingly reframed and re-planned, shifting in function from being a social space to being a refuge from the city (Kleinberg, 1999). This shift dates back to at least 1870s when H. H. Richardson was among the first architects to perceive the house as a refuge (Hildebrand, 1991). It was in the closing years of the Victorian era that the Prairie style was conceived.

2.2.3. Criticism of Victorian Architecture

Criticisms of the Victorian middle-class values came from at least two sources. First, there were the rural agrarian people who could not connect with those values, especially the emphasis on gentility. Second, there were a number of movements focussed on the re-examination of the role of machines in design.

For the first of these, the rural agrarian communities did not go through work-related gender segregation and the movement towards domesticity in the way the urban middle class did. In the mind of a rural observer, the foundation of the family was threatened by this change because the role of women was perceived to be reduced to the objects and ornaments in the parlour (McMurry, 1985, p. 271). Similarly, the concept of gentility did not become popular in rural agrarian communities either. The parlour space had already been abandoned or replaced by the "sitting room" (where all family members sit together) and in the rural house at the time, it became the focal space in the urban house (McMurry, 1985). The parlour was contrary to the spirit of rural economy: there was no use for it in a rural house as it would have remained an unused space for most of the year. For the same reason, there was no place for the idea of gentility.

The second source of criticism was aligned with movements that sought a more proper relationship between machine and design. Giedion (1962) argues that a differences between American and European industry in the nineteenth century was the functional simplicity of the former. American tools were more diverse and simpler, yet at the same time more functional. Accordingly, they were more suitable for machine production as well, probably because the relative shortage of workforce in the new world. However, this simplicity was not reflected in the residential architecture of the urban middle class. As mentioned previously, the urban middle class was attracted to machine-made replicas of luxurious and highly-decorated genteel furniture and other household objects which imitated the values of the European aristocracy (Twombly, 1979). In this milieu, a number of architects, notably led by Louis Sullivan, began to rethink the architectural trends of the time. These architects, usually called collectively "the Chicago School", were keen to simplify the architecture of urban buildings.

Regarding the functional aspect of simplicity, Sullivan was a supporter of the elimination of "unnecessary" elements in architecture. Ornament was one of the elements that he preferred would disappear from design for a long time as "it would be good for our aesthetics" (as quoted in Frampton, 1992, p. 51). Ideas such as this profoundly influenced Frank Lloyd Wright, who joined the studio of Sullivan and his partner, Adler, in 1889 at the age of 19.

Wright shared the enthusiasm for simplicity with Sullivan. He described simplicity as the ability to grasp everything as a whole with "one eye" (Wright, 1960, p. 48). Like Sullivan, he also desired to eliminate the "unnecessary" in order to simplify the relationships between the elements of architecture, from the arrangement of the spaces to the details and the character of the building (Wright, 1960). However, he emphasised the difference between simplicity and "plainness", which he considered "offensive". Plainness was considered as the simple visual appearance of an element, while "simplicity" was the simple systemic integrity between the elements (Wright, 1960, p. 47). For both Wright and Sullivan, the perfect examples of simplicity were natural organisms, especially plants. For example, Wright noted that a wildflower had a variety of shapes, colours, and parts while it is simple at the same time as it can be grasped as a harmonious whole.

While nature and its forms played an important role in the definition and representation of simplicity, nature also manifests another similarly crucial concept, that of *freedom*. One of the characteristics of being natural is to be free from external (and unnecessary) imposition. Therefore, a natural form grows freely, allowing it to fulfil its potential (Benevolo, 1971). The freedom which Wright and Sullivan perceived as embedded into natural forms is usually deemed an "organic" property (Wright, 1960). They applied this notion of the "organic" not only to nature but also to society. In Wright's opinion (1960), a society should be free from the artificial impositions of elites and rulers (whether political or religious). Accordingly, Wright believed that in the past people were enslaved by these higher ranks or their ideologies. However, in his time he saw the potential for the liberation of the individual.

The American people of the late 1800s would have seen themselves more as individuals than members of distinct social groups divided by family, ethnicity or religion (Pinnell, 2005). Wright (1960) hoped for such an individual who was supposedly uncontaminated by stylising biases and untainted by social orders. In this regard, he believed that the machine had been used to imitate or fake the past styles (such as Gothic or Renaissance) instead of instigating a new style suitable for the modern society.

For Wright, the two qualities of simplicity (with its associated notions of wholeness, functionality and intelligibility) and freedom (also organic-ness) were core principles of society and architecture. As such, he tried to incorporate these qualities into the design of the Prairie houses.

2.2.4. Principles, propositions and indications of Prairie houses

It was only in the mid twentieth century that Wright clearly outlined the principles of his Prairie style architecture, well after he designed his first Prairie houses and probably long after he had devised a framework for this style. In other words, it is debatable whether Wright was fully mindful of them when he designed Prairie houses, or when he ceased designing them, or even after revisiting the designs at later periods. The answer to this question is beyond the scope of this chapter, however it is the following principles that are considered to be properties of the style.

Wright defined the principles of Prairie architecture in three different wordings, which reflect three levels of abstraction. The first and the most abstract of these include *simplicity* (or *unity*), *plasticity* (or *continuity*) and the *nature of materials* (Wright, 1943).

1. Simplicity, as explained previously, initially referred to the wholeness of the building and the integral relevance of elements (Wright, 1960). Wright tended to apply this principle to all aspects of architecture from the appearance (forms, furniture, and ornaments) to the spatial configuration (functional programme to visual topology).
2. Plasticity can be explained as the intermingled connection between the elements of architecture in a way as to imply a continuous shift, rather than an abrupt separation. Wright considered plasticity as an organic feature, exemplified by human physiology where different layers of body tissues mediate between the interior and exterior of the body (Wright, 1960). It is also possible that the concepts of continuity and plasticity were perceived by him in opposition to the most despised feature of Victorian architecture, its external imposition.
3. The expression "nature of materials" reflects both simplicity and organic-ness. In summary, Wright (1960) advised using materials only for purposes for which they were naturally suitable. In other words, he advised against imposing a use for a material against its intrinsic characteristics. This definition is, of course, arguably subjective. It may

be better understood as the use of unadulterated materials, as he tried to use materials in their original constitution or form (not mixed or painted).

These three principles are further explained by six "propositions" and nine detailed "motifs and indications" about the style. The six propositions include (Wright, 1943, pp. 33-34):

1. *Simplicity* (as explained earlier with notions of unity and wholeness).
2. *Individualistic design*: Wright stated that "there should be as many kinds of design as there are kinds of people and as many differentiations as there are individuals" (quoted in Laseau & Tice, 1992, p. 48). This proposition is related to the idea of natural freedom, as the house design emerges from the characteristics of the individual rather than being imposed by an existing scheme. This is also a reflection of the late Victorian perception of the house as expressing the dwellers' character.
3. *Growth from the site*: Wright stated that the house should be seen as a whole with the ground beneath it. This serves both integral simplicity and of organic growth, while is also a reflection of plasticity.
4. *Natural colour and schemes*: This proposition is an aspect of the third principle (nature of materials).
5. *Nature of material* as explained previously.
6. *Having the character (identity) of a house*. The house should be intuitively understood as a "house" in single glance. As mentioned, the perception of the house changed into a family-friendly refuge towards the late Victorian era. Similarly, Wright defined the essence of a house as being a "shelter".

In addition to the above propositions, nine motifs and indications are reiterated in the literature about the Prairie house. These are less abstract and more detailed and visible than the themes in the previous two lists. Some of these indications clearly reflect the concerns about Victorian architecture explained in the previous section. They include (Wright, 1960, pp. 45-47):

1. *"Achieving simplicity by reducing the number of separate rooms to a necessary minimum".* It would have been "foolish" in Wright's opinion if five rooms were planned when three were enough. This indication would be more understandable when we consider that Victorian houses had a separate room for each function (Kleinberg, 1999) and that a number of them (especially the specialised parlour) were considered a waste.
2. *"Using of mono-material as much as possible"*.
3. *"Incorporating the heating and lighting systems so they become consistent parts of the architecture*".
4. *"Design furnishing with buildings as if they are organic parts of the house"*. He also added that *"the furniture should be of flat lines and rectangles so they are suitable for machine production"*. This demonstrates the late Victorian disfavour of the genteel furnishing culture, and their industrial replication for the purpose of aggrandising rather than functioning.
5. *"Eliminating the decorator"* as their job would not be necessary if the architecture of the house was well-designed.
6. *"Associating the building to the site"* as if they are parts of the same whole. This is similar to the third proposition (growth from site).
7. *"Eliminating the room as a box and the house as another [box] by making all the walls as enclosing screens flowing into each other. So they make one large enclosed space"*. This is one of the most acclaimed features of the Prairie house which contributed to the open-space architecture later in twentieth-century Europe. Wright himself considered it as a defining innovation using words such as nothing like this was designed before (1960, p. 44).
8. *"Setting the house on a platform (visible foundation) and remove the basement"*. Wright always denounced the underground basement and

tried to avoid designing it as much as possible (unless demanded by the client). He regarded the basement as a "cellar" without any use for modern life.

9. *"Harmonising all necessary openings to outside and inside with good human proportion and make their occurrence naturally*."

In the next section, the properties of the Prairie house are discussed regarding Victorian ideals and architecture and Wright's principles, propositions, and indications about house design.

2.3. General characteristics of Prairie houses

The Prairie style is usually considered to have emerged on the eve of the twentieth century (Frampton 1992). However, it is also argued that the style was triggered in two houses designed by Wright in 1893: one for himself, known as the Oak Park house, and the other for the Winslows (Figure 2.1c). Wright himself called the latter house his first real design (it was also his first independent commission) (Twombly, 1979; Brooks, 2006). Frampton (1992) and Pinnell (2005) consider that the Prairie style rose from Wright's two house designs for Husser (built in 1895) and Heller (built in 1899) as seen in Figures 2.1a and 2.1b. Alternatively, Whiffen (1969) identified the Bradley house (built in 1900) and Hickox house (built in 1901) as the start of the style. These houses are all considered to have many of the main features of the Prairie style.

In any case, all of these houses, more or less, shared general characteristics which are discussed in this section. The following characteristics are confined to elements of form (layout, fireplace and façade) and spatial programme or "function" (including the connection between spaces). This section focuses more on qualitative features which were identified in the literature. More specific or quantitatively identified features are discussed in the next section (2.4).

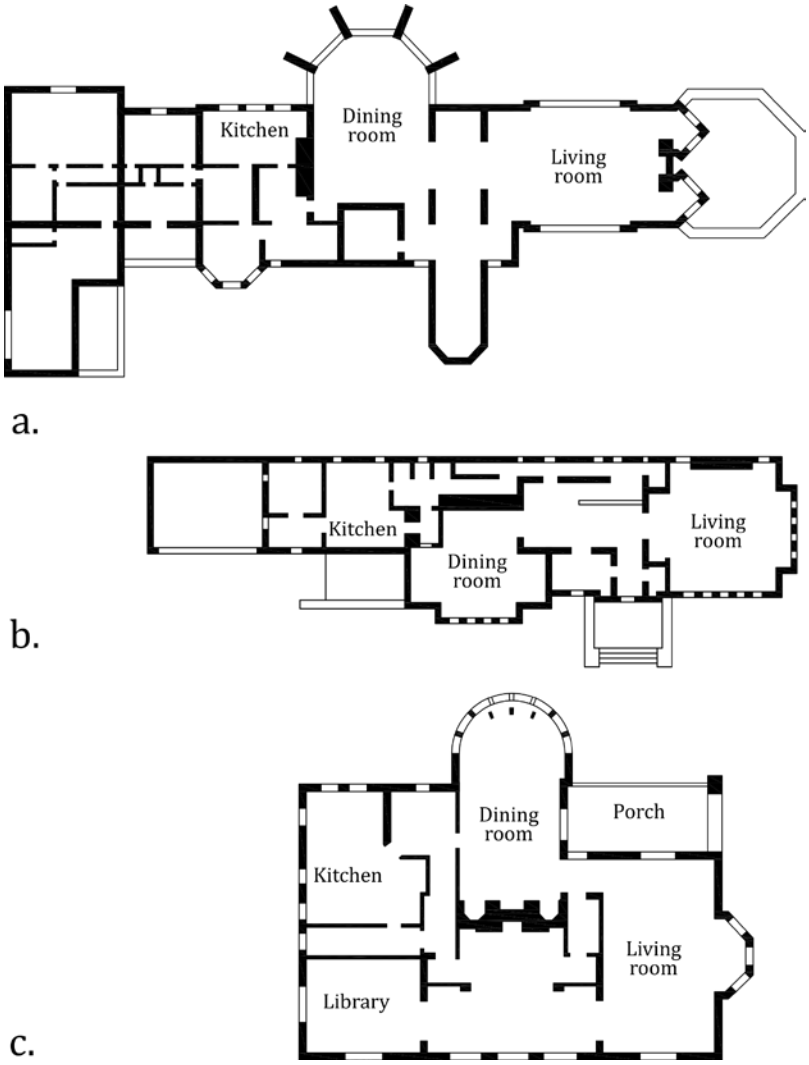

Figure 2.1. Schematic floor plans of three early Prairie houses, Husser (a), Heller (b) and Winslow (c), adopted from Pinnell (2005).

2.3.1. The layout of floor plans

The plan layout of the Prairie house is regarded as one of the most important characteristics of the style. The Prairie plan reflects its volume, which is usually a composition of interlocked rectangular blocks (Van Zanten, 2005). The blocks often intersect each other in the centre of the house that usually contains a hall and/or a fireplace. Ideally, in the plan, the composition of these blocks resembles a cruciform in both first (ground) and second levels (Chan, 1992) although the wings usually retreat inward in the second level (Figure 2.2). Therefore, the outline of the Prairie house was considered less solid than that of the Victorian house. This composition is usually identified as an innovation of Wright, as it is rarely observed in Victorian houses.

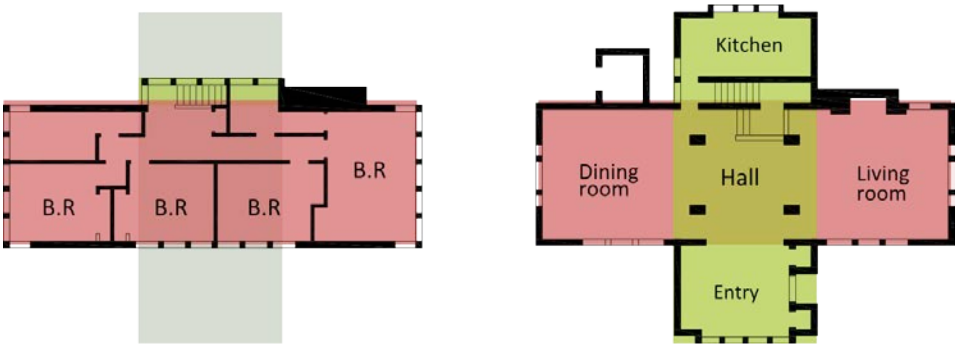

Figure 2.2. Walser house (1902): the cruciform layout of the first level (right) and second level (left). The plans are adopted from Futugawa (1987a).

The perfect cruciform plan (when the centre of opposite wings can form an axis) has been nicknamed the "windmill"; however, in some houses, the opposite wings of the cruciform are shifted laterally, giving the nickname "pinwheel" to that type of plan (Laseau & Tice, 1992, p. 34). Moreover, the rectangular blocks are sometimes so intermingled and displaced that the plan outline resembles a T-shape (Figure 2.3), as one wing is fully merged into the central square of the layout. In any case, the cruciform is accepted as the ideal plan for the Prairie house. It has been suggested that the cruciform composition of the Prairie houses was influenced by a few factors including lighting problems, spatial organisation and the forms in nature. In Wright's own writing, the house (i.e. its plan) is likened to a flower that blossoms out of its centre and explodes in all directions (Wright, 1943), a statement that reminds us of the principle of organic and free growth. In addition to this symbolic factor, Wright asserts that the expansion of wings in the house facilitates the lighting of spaces so that most of the rooms in the house have direct southern sunshine (Giedion, 1962).

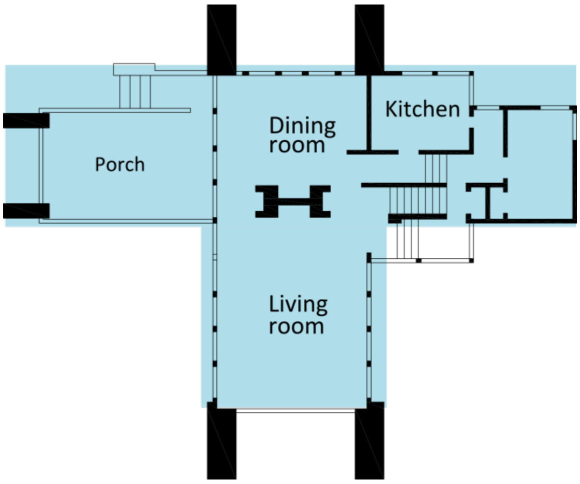

Figure 2.3. The T-shape floor plan of Baker house. The plan is adopted from Futugawa (1987b).

Nevertheless, it was widely discussed, including by Wright himself (1960), that the Froebel wooden blocks given to young children (including the young Wright) to foster their creativity, played a crucial role in the juxtaposition of the rectangular blocks in both plan and volume of the Prairie houses (Giedion, 1962; Chan, 1992; MacCormac, 2005). It is claimed that these blocks raised Wright's awareness of geometrical systems, improved sensitivity to 3D solids and voids, introduced the compositional possibilities of diverse elements, provided 2D patterns and 3D spatial volumes, and enabled the visualisation of the 3D implications of 2D drawings (Laseau & Tice, 1992).

Another possible source of the cruciform layout is Japanese architecture. In the same Philadelphia Exposition at which the Queen Anne style was presented to Americans, the United States was introduced to Japanese architecture. This led to a growth in popularity of Japanese art, artefacts and motifs among designers and the upper class. Ten years later, a number of Japanese architectural designs were published in Morse's 1886 *Japanese homes and their surroundings*. A particular plan of the Hō-ō-den[1] shrine with a cruciform layout was among the plans in Morse's book. Considering Wright's frequent praise of Japanese architecture and implementation of

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[1] Transliterated as Ho-o-den in most of literature.

other Japanese elements (e.g. screen wall) in Prairie houses, it is argued that, despite Wright's denial, the cruciform layout of the Prairie houses is partially influenced by this shrine's plan (Whiffen & Koeper, 1981; Laseau & Tice, 1992). Nevertheless, the Japanese shrine was not the only cruciform plan available to Wright. As mentioned in section 2.2.2, Bruce Price had already been incorporating this idea in his late 1880s domestic architecture.

Another aspect that contributed to the cruciform layout is the idea of the foursquare house (Pinnell, 2005). As explained earlier, the term "foursquare" refers to the four crucial zones of the house, including kitchen (service area) and living and dining rooms, and entry (or library or any other large space). These spaces represented the minimum functional requirements of the American lifestyle of late 1800s. The four wings of the cruciform shape are in fact the dedicated spaces to these functions. The functional programme of the house is discussed in the following sections.

Frampton (1992) revealed another significant aspect of the cruciform. In the late 1800s the wider society and the architectural community were still flirting with the classical orders of architecture (notably, the concept of symmetry). The symmetrical order was apparently the symbol of a functional family (Twombly, 1979). In this regard, the front façade of the Prairie house (and its volumes) were arranged so that it looked more orderly and symmetrical. This side of the building usually included the entry, living, and dining rooms. On the other hand, the architect felt free to abandon this symmetry in the back façade where the service area was located (Figure 2.4). However, as mentioned previously, the rear asymmetry of the house pre-dates Wright, at least to the works of Richardson in the late 1870s (Frampton, 1992).

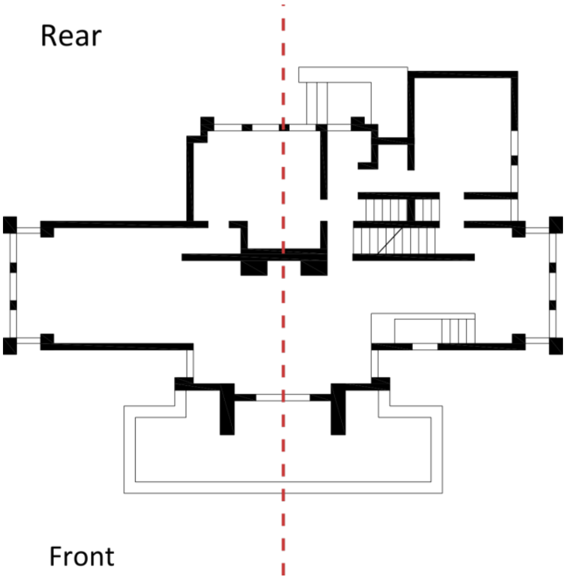


Figure 2.4. The third scheme for Harvey Sutton house: the element of symmetry is present from the front view (down) while the rear side (up) is asymmetrical. The plan is adopted from Futugawa (1987b).

While the layout of the Prairie house is associated with the relatively freeform expansion of volumes, it is constrained to a rigid *grid system*. This is because Wright was keen to introduce machine-made systems into his works in order to harmonise it with the modern space (Curtis, 1996). The goal of the grid system was to simplify the construction process to use machine-made elements.

The grid system was typically in the form of a horizontal tartan-shaped lattice (Pinnell, 2005). Chan (1992) reports that the proportion and dimensions of the grid varied along with the materials and purposes of the buildings. For residential buildings, the grid's minimum dimension was around 4 feet for wooden structures and 4 feet 6 inches for brick structures. The smallest elements, such as stair lengths, doors, and closets usually fitted in these minimums. Table 2.1 shows the grid proportions of the Prairie houses.

Table 2.1. A summary of grid system units of the Prairie buildings (adopted from Chan, 1992. The metric equivalents are added by the author).

Material	Grid system size
Wood	4'-0" (~121cm) and 16" (40cm) centre for length of the lath
Brick	4'-6" (~136cm)
Concrete	7'-0" (~213cm) 16" (40cm) unit for lumber work
Concrete support and floor slabs	4'-0" (~121cm)
Pre-cast blocks	16" (~40cm)
Concrete and brick	20'-0" (6.1m)

2.3.2. Fireplace

The fireplace in the Prairie house had multiple symbolic and functional roles. The first thing that made Wright's fireplace important was its sharp contrast with the common treatment of fireplaces in earlier houses. Wright (1960) asserted that the earlier "mantels" were very small and produced little heat (we might assume that Wright considered them as mainly decorative). On the other hand, the Prairie fireplaces were comparably massive, robustly built of masonry material, and clearly visible from most open parts of the first level. In addition, its vertical extension cuts through the second floor where it joins with a smaller fireplace and then continues through the roof with its solid appearance contrasting from the low profile volume of the house in both stance and material.

Another important aspect of the fireplace in the Prairie houses is its symbolism (Twombly, 1979). Fire, and its holding place, the hearth, are the main places where the members of a family would gather around throughout history. In the cold winters of the Midwest United States, this might have even meant more than symbolic importance, as it served as a practical materialisation of the concept of "shelter". The hearth, therefore, symbolises the family itself. Wright used the metaphor of a tree for buildings, as it is rooted in the ground while possessing the capacity for growth and change (Curtis, 1996). In this regard, the fireplace is likened to the stem and root of the tree, a robust and stable feature while the rest of the house is spread freely on the ground much like the tree's foliage.

It is important to note that not all the fireplaces of Wright's houses are central. There are several houses with fireplaces located on the exterior wall of the living room, that is, on the side of cruciform wing (Figure 2.2. in section 2.3.1). Nevertheless, the fireplace would still be a focal point for the living room which it serves.

The massive fireplace first appeared in the 1893 Winslow house and Oak Park studio (Twombly, 1979). Like the broken axes, it was also a feature which apparently surprised visitors on their viewing of the house. The origin of such a fireplace is sometimes attributed to a Japanese architectural element called *toko-no-ma* (Frampton, 1992; Nute, 2000). *Toko-no-ma* is an alcove-like recession in a room which hosts important guests or objects (Nute, 2000). Naturally, it is also the most decorated part of the room, having an almost sacred status. Another possible origin of this type of fireplace is the Queen Anne style with its prominent fireplace over the hall (see 2.2.2).

Wright had been familiar with oriental designs through publications and exhibitions (such as the Chicago exhibition in 1889). He had supposedly borrowed and modified the Japanese motif into the fireplace with the same focal attention. Furthermore, the fireplace is not the only element he allegedly took from the Japanese (or generally "oriental" architecture, including the Chinese and North African). The screen partitions, the lattice wooden frames, and ornamental plant motifs are other examples of the "oriental" influence on his design (Twombly, 1979).

2.3.3. The façade and exterior appearance

The significance of simplicity and natural growth have already been discussed as has Wright's guidelines about the appearance of the building in regard to the site. As for the exterior appearance of the house, Wright tended to relate the house to the earth as much as possible by emphasising horizontal planes and lines (Frampton, 1992; McCarter, 2005). This is obvious in the Prairie houses, especially when compared to the earlier Shingle style in the Victorian era. There is almost no attic space in Prairie houses, allowing them to have a low-pitched roof (Wright, 1960). To emphasise the horizontality, the low-pitched roof was accompanied by horizontal casement windows, the foundation platform (as a consequence of removing the basement), and the flat and broad terraces and planting around the house. As mentioned earlier, one of the reasons for these terraces was to endorse the principle of plasticity.

There is one element in Prairie houses that is conspicuously vertical – the chimney that is the extension of the fireplace beyond the roof. When the chimney is in the centre of the house (Benevolo, 1971), it represents an integrated set of purposes. Apart from being the compositional centre of the house, it is also a structural centre, being made of robust material. This architectural element will be discussed later in this section.

2.3.4. Spatial programme of Prairie houses

The spatial organisation of the Prairie houses should be understood together with its formal composition, especially as Wright was also a supporter of Sullivan's "form follows function" motto. The layout of the Prairie houses was likely influenced by the juxtaposition of its four crucial functional spaces. In this section, we first discuss how these spaces and other less common spaces were arranged in the house. Then we review the visual experience in these spaces.

As mentioned, the Prairie house belongs to the general type of "foursquare" houses with four main functional zones including the living room, dining room, service area, and the entry (or library) in the first level of the house (Pinnell, 2005). The other spaces inside the first floor are of two types. The first type includes a number of small rooms for auxiliary functions to the main four functions. For example, reception space and coatrooms connected to the entry zone (e.g., in Francis Little house, Figure 2.5). The dining room is rarely divided by separating a smaller breakfast room (as in Heurtley House).

The service zone has usually the highest number of these additional spaces. Apart from the main service space – the kitchen – there is usually a pantry space. There may also be bathrooms, stores, closets, a maid's room and even a small dining room for servants. In addition, we should add a staircase to upstairs and the guest room to this list, as they are usually located in the service area if in the programme.

Figure 2.5. The subspaces in the four main zones in Francis Little (left) and Kellogg (right) houses.

The second type of spaces occur in what could be called "extended" Prairie houses. They include a number of social spaces which are large enough to comprise the entire area of a wing of the cruciform layout. Rooms such as a library, music room, studio, or gallery are examples of this extended type.

The positioning of the spaces is depended on several factors. Considering Wright's concern over the availability of sunlight from the south for social spaces, the service area usually faces north (Chan, 1992), allowing the social areas to gain better daylight. In other cases, the service area is placed on the west wing. The living room always had a southern façade, making it improbable as a northern wing. The entry is usually on the eastern or southern side. The dining room and service area were never located in opposite wings (regarding their necessary direct connection). As mentioned earlier, another factor was the orientation of the house on the site that could determine the front more-symmetrical façade and rear asymmetrical service area.

In addition to these indoor spaces, there are usually porches or terraces around the house. They are often placed on the end of the cruciform wings and so they also contribute to the horizontally stretched expression of the house. They also act as a buffer between the mass of the house and the void of outside, supporting the principle of continuity. Figure 2.6 shows porches in three wings in the proposed plan for the Francis Little house (in 1908).

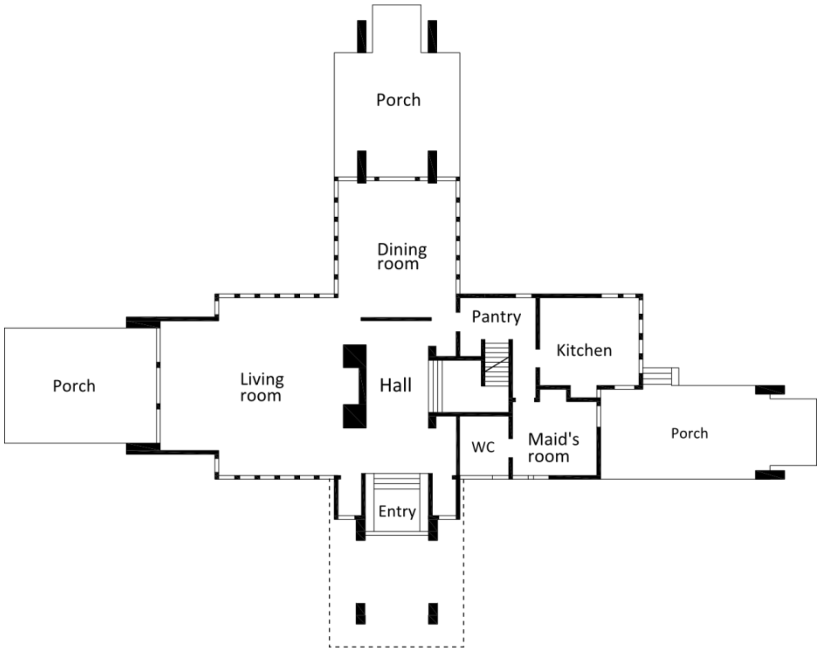


Figure 2.6. The full-featured cruciform plan with terraces at the end of all wings in the proposed plan for Francis Little's house.

Overall, there does not seem to be an essential difference between the functional programme of the Victorian and Prairie houses at the first floor level, despite the alleged simplicity of latter. Both styles have simple and extended plan schemes. Nonetheless, the main differences may be summarised as follows:

- The Victorian term "parlour" has disappeared and been replaced by the "living room" in Prairie houses.

- The entry space makes up a full "square" in some Prairie houses while the entry is a small space or portion conjoined usually to the hall in Victorian houses.
- There are usually more porches (or terraces) in the Prairie house than in a Victorian house.

The second floor of Prairie houses mainly included the "private zone" (Laseau & Tice, 1992) of the bedroom and occasionally a smaller living room. The bedrooms were often equipped with a closet and sometimes their own private bathroom. In a small number of houses there is a basement, usually containing heating equipment, stores or the laundry. As mentioned previously, the lack of basement and attic spaces is one of the main differences between the spatial programmes of the two styles.

In addition to the "functional" spaces mentioned above, there are a number of circulatory spaces in the buildings. The hall, usually located in the centre of the cruciform layout, is the most important of these. Due to its centrality, the hall often has access to non-service zones (the living, dining, and additional rooms and entry). From early designs by Wright (e.g., Winslow House in 1893) the hall also played a role in visually presenting views of adjacent spaces (MacCormac, 2005). In some houses the hall is not directly connected to the service area. There is also a hall in Victorian houses with similar function and connections to other spaces, however, the Victorian hall was usually in the corner of the house (as a "square") rather than the centre.

The largest spaces in the Prairie plan are normally those which comprise a whole cruciform wing. In the simple Prairie house, it is either the living room or dining room. In the extended houses, the additional spaces may also be the largest. The absolute size of these spaces differs dramatically between houses. After these spaces, the hall, if it exists separately, is usually the next largest. In the service area, the kitchen is often the largest space in the service area, although the servant's dining room, the heater room or "den" can also be comparable if present in the plan.

2.3.5. The topological properties of Prairie spaces

This section discusses how spaces in a Prairie house are connected to each other, in regard to both access and visual connections. The scope of this section is limited to the qualitative analyses of the Prairie houses as found in the literature. The subsection is divided into two parts, the first (part *a*) discusses physical adjacency and access between spaces, and the second (part *b*) reviews the visual connections.

a) Adjacency and access between spaces

One of the essential topological features of Victorian houses was the food axis. In this regard, the Prairie house retained the Victorian order. The dining room is the main room which requires the most connections to the service area. Therefore, in many houses, especially those with a simpler service area, the service area is directly connected to the dining room rather than to the hall (Figure 2.7). The connection of the service area with the dining room is itself subject to the food-axis hierarchy. It is very likely that the pantry (if present in the plan) either mediates between the kitchen and the dining room, or is closer to the dining room than the kitchen. Similar to Victorian houses, the living room is not usually directly connected to the service area.

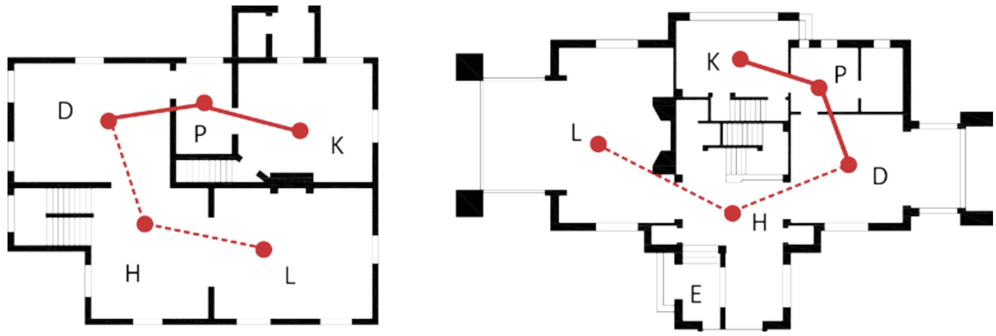


Figure 2.7. The common food axis hierarchy (solid lines) in Victorian (left) and Prairie (right: Little House) houses and its relation with the rest of the house (dashed lines).

Behind the kitchen, there are extra spaces which serve the servants or the service area in general. Spaces such as an extra dining room, bathrooms, store closets, and laundry are among these spaces. Finally, the servants' bedrooms (or maid's rooms) are often located at the deepest parts of the service area.

The connection between these spaces is either provided by separate corridors or the spaces themselves. Spaces such as the kitchen, pantry, and servants' dining room can also play the role of a corridor to their adjacent spaces. Conversely, there is less likelihood of a corridor in the other three areas of the cruciform layout. The spaces are large enough to share a portion for circulation, although in some cases the central hall is so narrow that it acts only as a corridor.

Despite the hall's centrality, the connection between adjacent wings is often direct. This is mainly due to Wright's eagerness to open the corners of rooms, and so the adjacent wings are often also connected via their corners. This corner opening is more than just a practical connection and it has roots in Wright's architectural theory and contributes to spatial experience as discussed hereafter.

b) Visual properties and connections of Prairie spaces

The visual properties of Prairie spaces can be studied from different perspectives such as their lighting, vistas and visual connections, colours and materials, and geometric features of the rooms, among others (Hildebrand, 1991; Laseau & Tice, 1992; Michaelsen, 2006). In this section, we limit the notion of "visual property" to the topological and geometrical features of the floor plan.

In Wright's opinion, one of the obstacles to achieving the necessary social integration in a Victorian building was the design of spaces as enclosed and isolated boxes (Wright, 1960). One of the reasons for this isolation was structural, arising from the limited strength of materials (Pfeiffer, 2003). However, by the late 1800s many structural advancements had already occurred. Wright tried to capture the spatial design of the house as a whole connected space, free from obvious structural limits (Wright, 1960). This wholeness was not necessarily about directly seeing more space but probably a sense of connection. According to Brooks (1979, p. 9) the Prairie houses showed a degree of "mystery" by not resolving "all visual questions at once".

Wright and other Prairie architects tried to minimise the "box-like" properties of rooms. This was done by reversing the definition of the wall and its openings. For Wright's doors and openings of the earlier houses were like holes cut into the room's walls (Wright, 1960). To reject this, Wright tried to make the walls look like a partition screen in the middle of the unified space (Figure 2.9). In this regard, Wright usually placed openings at the corners of the room's rectangular outline. This supposedly disconnected the walls from each other and emphasised their perception as separate elements while at the same time reducing the perception of a well-bounded or enclosed void within those walls. Nonetheless , the bedrooms were exempt from this treatment as Wright (1960) described them as "sleeping boxes" because their privacy mattered more than other things.

Room corners, walls, and openings were designed to emphasise the idea of simplicity (i.e. holistic perception of the house space). However, they also contributed to the plasticity of the space as well. The corner opening treatment shifts the axial focus of the room from the static and classic centre to a smoother corner opening, a change which supports the idea of plasticity (i.e. smooth transition). This is sometimes called the "diagonal plan" in the Prairie style (Pinnell, 2005). The opening of corners also allowed the spaces to interlace or "flow" into each other (Michaelsen, 2006). In earlier Prairie houses, the shift from the classic orthogonal axes to the diagonal axes was realised by using rotated squares, whose corners were cut to create openings (Levine, 2005). However, in later periods, these rotated squares were reduced to projections in the end of the rectangular blocks.

The breaking of the axes first occurred in Wright's own house in Oak Park, built in 1893 (Twombly, 1979). One of its effects on the user's experience was soon reported as that it was impossible to go through the length of the house in a straight line. Walking in a Prairie house must have been more adventurous than a common house of that time.

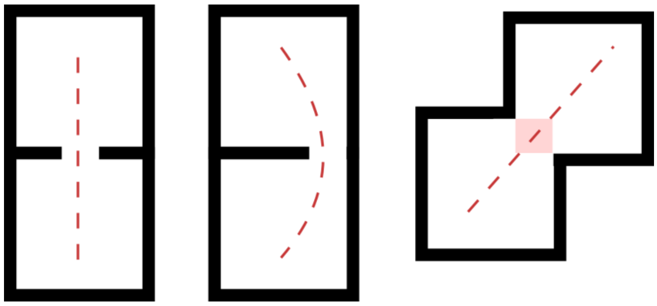


Figure 2.8. Static central axis (left), the smooth flow axis (middle) and diagonal plan and axis (right)

As mentioned, late Victorian society perceived the house as a refuge from the urban life, a quality embodied in the transformation of the Victorian parlour into the post-Victorian living room (McMurry, 1985). In this regard, Wright's spaces are said to draw their inhabitants closer to each other through planning strategies (Maddex, 2002), and thereby increase social contact (Twombly, 1992). Whereas the first of Wright's strategies was concerned with visual connectivity, this second is about the use of space. However, there are at least two opposing theories explaining how Wright accomplished this aim. Maddex (2002) asserts that the Prairie house offered more opportunity for inhabitants to circle around and through the house, especially by way of the living areas, while Twombly (1979) claims that it was almost impossible for a person to pass through all spaces without returning to one, so that dwellers were required to revisit certain spaces where they would cross paths with other inhabitants. While admitting that Twombly's (1979) argument is mainly concerned with the early Prairie houses by Wright, and Maddex (2002) encompasses a broader set of these works, there remain both similarities and differences in their arguments about movement through space.

Another aspect of visual connection in Prairie houses is the connection between indoor and exterior spaces. This connection is especially noted in regards to the living room. Laseau and Tice (1992) argue that there is a pattern of vistas present in these spaces, beginning from the fireplace, covering the living room and extending beyond its windows to the exterior spaces (Figure 2.9). This position is reflected in Hildebrand's (1991) view that the fireplace acts as a refuge while it provides a visual prospect to the rest of the house and outside (see also 2.4.3).

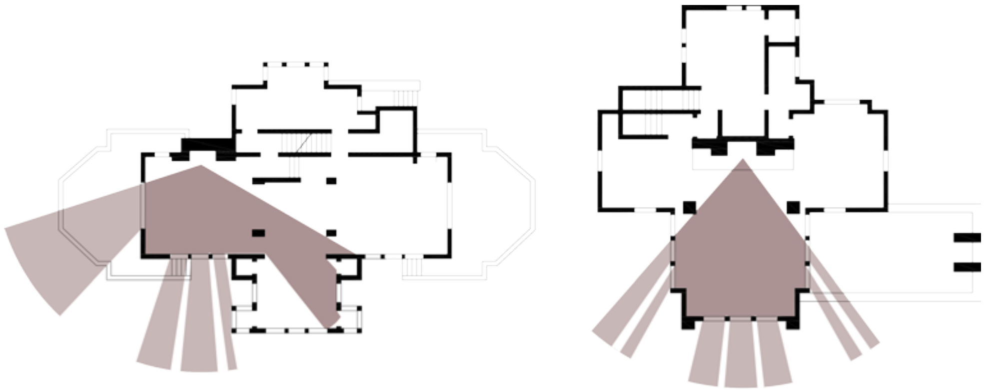


Figure 2.9. Examples of vista originated from the location of the fireplace.

In summary, Wright's Prairie houses are considered more holistic and integrated compared to their Victorian predecessors. Similarly, the main rooms in the Prairie houses are less isolated and more integrated into the whole of the building, presumably because of the corner-opening treatment and the diagonal planning. These properties also allegedly made the Prairie houses friendlier and more intimate to support intra-family social life. Another potential reason for the latter property is that there is more circularity inside a typical Prairie house.

2.4. Specific studies on the layout and topology of Prairie houses

As discussed in the previous section, most past studies on Prairie houses are limited to qualitative approaches which either enumerate the characteristics of the houses or, consequently, speculate upon other characteristics.

However, there are several quantitative studies focusing on either forms or spatial topology of these houses which are discussed in this section.

The section contains five studies of the layout of the Prairie houses including three typologies by Laseau and Tice (1992), Chan (1992) and Pinnell (2005), a shape grammar by Koning and Eizenberg (1981), and an application of the *Prospect and Refuge* theory by Hildebrand (1991) which has been furthered by more recent studies. The first three studies (the typologies) are combined in one subsection. There are also other studies with a quantitative approach towards the physical forms of the Prairie houses (e.g., fractal geometrical analysis of façades by Vaughan & Ostwald, 2010, 2014; or “weaves” grid geometry by Laseau & Tice, 1992); however, they are not considered relevant to the spatial topology or interior design of the Prairie houses and thus they are not discussed in the following subsections.

2.4.1. Spatial composition, and typology of Prairie houses

In the previous subsections the overall layout, the positioning of the fireplace and the spatial programme of the Prairie houses have been discussed. In this subsection, the relationship between them is explained in regard to the composition and arrangement of spaces and elements in the Prairie house plans. The focus of this subsection is only on the ground floor where the main four “squares” of the house are located. There are also differences between the layouts of the Prairie houses. For example, in some houses the ideal cruciform is cut into a T-shape plan or in some other houses, the fireplace is moved away from the centre of the house. This suggests that there are different types of Prairie houses in regard to the composition of spaces and elements. The earliest differentiation was between the so-called pinwheel and windmill plans as mentioned in 2.3.1, which focused more on the juxtaposition of blocks rather than spaces. While other similar differences have been identified from the earliest of studies on the Prairie houses, three particular studies by Laseau and Tice (1992), Chan (1992), and Pinnell (2005) propose a detailed typology of the houses. These typologies are discussed here.

a) Laseau and Tice

Laseau and Tice (1992) provide an analysis of the forms and geometry of buildings designed by Wright during his career. They suggest that most buildings designed by him fit into three types: *tower*, *atrium*, and *hearth*. The first two types were mostly applied to public or high-rise buildings and so are not within the scope of the present research. On the other hand, the third type, hearth, was mainly represented in Wright's houses. The hearth type captured the idea of domestic life and having roots in the earth.

The hearth type was subdivided into four secondary types based on the abstract layout of the house. The four types are cruciform (and its T-shape and L-shape variants), pinwheel, compacted (rectangular), and linear. Nevertheless, Laseau and Tice (1992, p. 34) also suggested that the cruciform was the ideal layout of the hearth type. The cruciform layout could be further extended by adding blocks to the end of its wings in larger houses. While Laseau and Tice pointed to the relationship between the functional zoning of the houses and their layout, they did not elaborate on this relationship.

b) Chan's typology

Chan (1992) presents a detailed study of the characteristics of Prairie houses. One part of that study involves the designation of three types of Prairie houses based on the arrangement of the main functional zones and the library in the cruciform layout. Therefore, the house layouts would look like an arrangement of five rectangles, one of which is in the centre with the remaining four placed around it to form the cruciform shape. The centre rectangle is the hall or a similar space which includes the fireplace. The three types are as follows:

1. Type 1: the living room and service area (kitchen and servant's rooms) are in the opposite wings of the cruciform shape. The dining room and the library comprise the other two opposite wings. The hall, being in the centre rectangle, mediates between opposite wings. It is

possible that some parts of the service area merge with the dining room in this type.

2. Type 2: the entry complex (entrance and reception) replaces the library. In other aspects, this type is similar to the Type 1.
3. Type 3: differs from the previous two as the living and dining rooms make opposite wings, and the service area is opposite the entry complex. However, other features, including the penetration of the service area into the dining room, and the centrality of the fireplace, are similar to the first two types.

Furthermore, Chan considers a T-shaped version of each type in which one wing of the cruciform recesses into the centre of the cruciform and takes the place of the central hall. In types with an entry (1 and 3), the entry complex is excluded and so the central hall-fireplace space remains the same as the cruciform version. However, in type 2, it is the living room which replaces the central space although the fireplace is still present. Figure 2.10 shows the types in both versions.

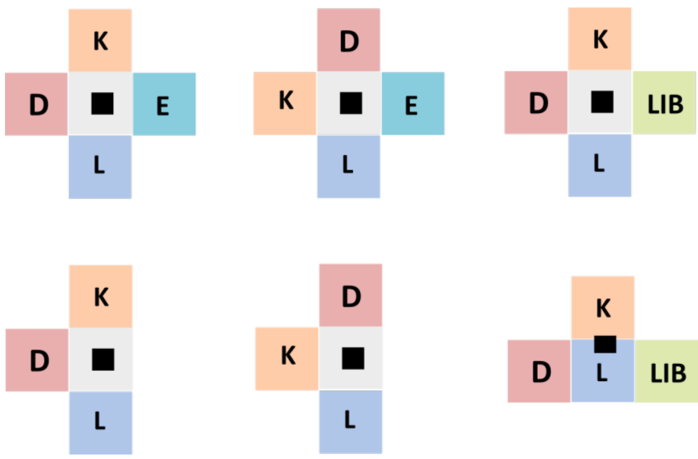


Figure 2.10. The classification of Prairie houses by Chan (1992). The full cruciform organisation (above) and the T-shape version (below)

c) Pinnell's typology

Pinnell (2005) proposed a typology of Prairie houses plans based on the composition of the functional zones and the placement of the fireplace. Unlike Chan's approach, Pinnell's typology is based only on the main four functional zones (living and dining rooms, kitchen or service, and the entry), so excludes the library. In his typology, there are two basic types in regard to the zone (the dining room or kitchen) which is placed in the opposite wing to the living room (Figure 2.11). Type I is considered a “centripetal” type where the opposing dining and living rooms create a strong “static” axis around the compositional centre of the house.

Type I is then categorised into two subtypes (IA and IB) based on the position of the entry. In subtype IA, the entry and the service zone are beside each other, betraying the cruciform layout. In subtype IB, the entry is opposite the service zone and so the ideal cruciform plan is created. Each subtype itself is divided into two further subtypes based on the position and orientation of the fireplace. In subtypes IA1 and IB1 the fireplace is parallel to the cruciform axis passing through the dining and living rooms. Usually, this means the fireplace is attached to an exterior wall. In subtypes IA2 and IB2, the fireplace is located on the dining-living room axis and faces the living room directly or by way of the hall space. In this case, the fireplace is usually located between the living and dining rooms.

In Type II, the living room is located opposite the service zone (kitchen) instead of the dining room. Pinnell calls this a “centrifugal” layout. Similar to Type I, there are also further subtypes for Type II in regard to the position of the entry. In subtype IIA the entry is opposite the dining room and so makes the cruciform shape. In subtype IIB, the entry is located beside the dining room. However, it is arguable that this can be regarded as a distorted version of subtype IB2 as the living and dining rooms mirror each other by the weak entry-service axis.

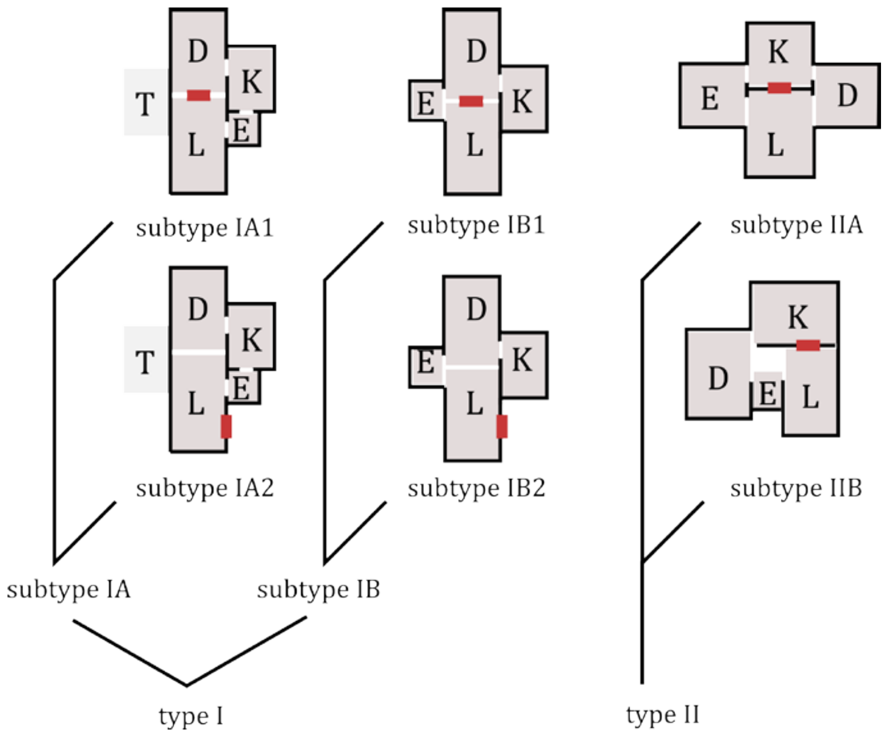


Figure 2.11. The schematic typology of Prairie houses proposed by Pinnell (2005). The letters stand for the main spaces (living room, dining room, kitchen, entry and terrace/porch). The red rectangles represent the fireplace.

The three typologies have similarities and differences in both their approach and outcome. An important difference is the consideration of the library as an indicator of a separate type in Chan's typology, while Pinnell's types do not feature this space. Another important difference is the limitation of Chan's types to houses with a central fireplace while the position of the fireplace is essential for the definition of subtypes in Pinnell's typology. While the typologies share the attention paid to both functional zones and layouts, it seems that Chan's types are more layout-oriented. For example, the T-shape layouts are simply considered a variant of cruciform layouts in Chan's, without discussing the functional difference in regard to the missing entry or hall in the T-shape layout. In contrast, the T-shape layout of Pinnell's typology is explained by the entry's positioning beside the service zone.

2.4.2. Shape grammar

Koning and Eizenberg (1981) developed a *shape grammar* to capture the design of Wright's Prairie houses. A shape grammar is a set of transformation rules which are applied recursively to an initial usually-simple shape to reach a final elaborate shape. A shape grammar should be able to regenerate the samples of the style or design corpus it represents.

The shape grammar of the Prairie houses was based on a corpus of 13 houses designed by Wright between 1900 and 1909. Koning's and Eizenberg's (1981) grammar also benefitted from Wright's design principles, most importantly, the floral expansion of the volumes from the centre. The central fireplace was thus the initial shape. The grammar consisted of a set of additive and substitution[2] rules. The additive rules were used to add elevated rectangular blocks to develop the cruciform plan layout, step by step. Meanwhile, the substitution rules are used for minor details such as corners and roofs.

This shape grammar was limited only to the positioning of the volumes (the rectangular blocks) and the exterior details (roofs and corners). In addition, the base corpus only included the houses with strong cruciform and central fireplaces. This central fireplace comprised the starting point (the initial shape) of the grammar as in Wright's own suggestions. Then other blocks are added sequentially around this centre. For this purpose, the grammar includes some semantic basics by initially considering the four functional zones – living area, service area, bedrooms, and terraces – as four rectangular elevated blocks with a minimum side ratio of 1 to 4. Figure 2.12 illustrates the divergence of alternatives generated by the grammar's layout-related rules.

[2] Additive grammar is a shape grammar in which a shape is added to the existing set of shapes. Substitution grammar is the process of substituting a shape with another shape (Knight, 1999).

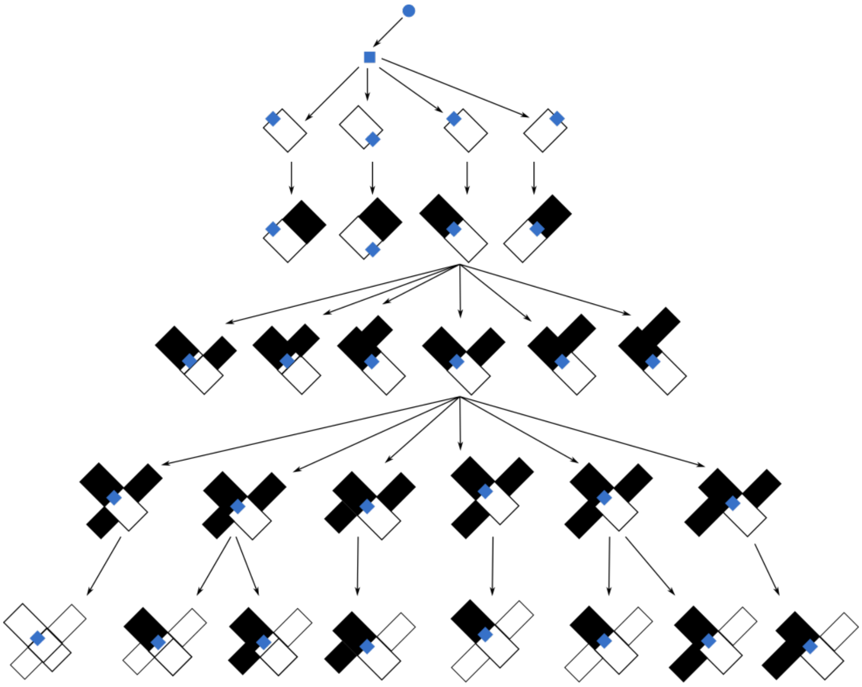


Figure 2.12. The divergence of Prairie house generated by shape grammar (adopted from Koning and Eizenberg 1981). The blue square represents the central fireplace.

This grammar does not appear to have been developed to take into account more detailed issues, especially interior settings. The interior of the generated samples was manually drawn by the authors themselves. Nevertheless, the main goal of their grammar, as a pioneering study, was to demonstrate the capabilities of shape grammar. Nevertheless, Benros and Hanna (2012) also proposed a generic grammar which was aimed at capturing different styles and designs, including their interiors. One of their cases was the iconic Prairie design, the Robie house (built in 1908). However, their study used a Prairie house only as a case, rather than as a focus.

2.4.3. Prospect and refuge analysis

In his book *The Wright Space* (1991), Hildebrand investigates why designs by Frank Lloyd Wright (both Prairie and later) are so pleasant and praised. He approaches the designs through the environmental theory of *prospect and refuge*, proposed by Appleton (1975). In summary, this theory considers that humans have evolved to seek environments with two certain properties. The first one, *prospect*, is a place from which the observer has an opportunity to see a broad space. The second property, *refuge*, is a place where a person can hide their presence. The combination of both properties would provide a survival advantage for an animal or person who can set for hunting without being hunted. Appleton argues that such combined criteria would be intrinsically appealing for a human that is (in Hildebrand's opinion) irrelevant to what function the space serves.

Hildebrand argues that Wright's houses, including those in Prairie era, fulfil these criteria. While revisiting Wright's notion of "house as shelter", Hildebrand considers that a combination of glazed and stained glass, layers of fences and terrace edges around the building, and overhung roofs has made a protected boundary, resembling that of refuge. Furthermore, the emphasised fireplace in the heart of the house endorses the sense of refuge provided both by the symbolic and functional purposes of the fire.

For the prospect side, Hildebrand notes that the house is located in the middle of the prairie landscape (though sometimes metaphorically). The main floor is visibly elevated, a property associated with prospect. The "open plan" also allowed a number of interior vistas, while the covered terraces provide outdoors vistas. Appleton (1975) asserts that spontaneous assessment of environment is essential to the survival of a species. This is parallel to Wright's idea that the space should be grasped through "one eye" (Wright, 1960).

Hildebrand demonstrates the criteria of prospect and refuge in a dozen Prairie houses in a qualitative manner. To investigate it quantitatively, Ostwald and Dawes use isovist properties (a part of space syntax theory) to investigate the features of the prospect and refuge theory in Wright's designs: Their first study (Ostwald & Dawes 2013) examined Prairie Houses, finding only relatively limited evidence of a pattern of prospect-refuge characteristics. In the second study (Dawes & Ostwald 2013a), the representative Heurtley House was analysed. They found that the isovist measures of properties broadly match the predictions of Hildebrand. Their next study extended this approach to Wright's textile-block houses (Dawes & Ostwald 2014a), and the one after to his Usonian houses (i.e. Wright's designs after 1936). In the latter paper, they found that only one of the isovist measures (isovist area) corresponded to the expected prospect and refugee pattern (Dawes & Ostwald 2014b). They have also analysed (Dawes & Ostwald 2014c) the isovist properties of the living rooms in 17 houses by Wright, including the five Prairie houses (Henderson, Heurtley, Cheney, Evans, and Robie). The results again generally supported Hildebrand's notion of an existing spatial pattern in regard to the prospect and refuge theory (although they observe that the pattern might have been overstated because of the exemplarity of the selected case).

Both Hildebrand's qualitative work (1991) and the case study series by Dawes and Ostwald demonstrate certain properties and patterns of Prairie houses in regard to the prospect and refuge theory. However, they do not provide a comparative measure, particularly to preceding Victorian houses.

2.5. Critical review of the Prairie studies

So far, this chapter has presented a survey of the literature on the Prairie style. A recurring theme has been the ideas and principles originally proposed by Wright himself. While the previous sections did discuss both proposed principles and identified characteristics of the Prairie houses, the relationship between them was less focused. This chapter also raises several questions:

- In what houses did the ideals, principles, and characteristics manifest themselves?
- How were the characteristics identified or possibly measured in those houses?

These two questions pertain to the methodology of the existing studies. The first question might have been crucial for the definition of Prairie houses and the case selection for any case study involving Prairie houses. The second question scrutinises the relevance and reliability of the applied methods (and hence their outcomes) in the existing literature. In this section, these two questions are briefly addressed in two respective subsections.

2.5.1. The issue of defining Prairie houses

Frank Lloyd Wright apparently considered a set of principles and ideal features in the design of the Prairie houses. These are reiterated by several historians as the characteristics of the Prairie style. For example, the cruciform layout and the central fireplace are almost always included in these characteristics. However, the Martin house (built in 1902) is neither cruciform nor has a central fireplace. There are many other houses which do not feature these features (for example no cruciform plan; like the much praised Heurtley House, or not having central fireplaces like the perfectly cruciform DeRhodes and Barnes houses). Such a mismatch occurs with several other characteristics and principles as well.

In this regard, it is worth questioning whether a house should reflect the principles in order to be considered a "more" Prairie house. For example, the six proposed types and subtypes of Prairie style by Chan (1992) all possess a central fireplace. Similarly, the shape grammar by Koning and Eizenberg (1981) is based around a central fireplace. Hildebrand's (1991) analysis of Prairie houses also emphasises fireplaces. On the other hand, Pinnell's typology (2005) includes houses with a lateral fireplace also as a type of Prairie house. While neither approach denies the Prairie-ness of houses which do not feature the whole set of principles and characteristics, they would influence the consideration of houses as representative in case studies, as they did for the corpus selection of the shape grammar (2.4.2).

2.5.2. Claims and ideal features

The previous two sections (2.3 and 2.4) reviewed the literature regarding the architectural elements (plan, spatial organisation, etc.) of the Prairie houses. This subsection presents a summary of the features of physical (layout) and spatial (topology) form claimed for the Prairie houses, especially in comparison with the residential architecture the Victorian era.

Subsection 2.2.4 presented a number of principles for the Prairie houses which were proposed by Wright himself. Simplicity, plasticity (or continuity), and the nature of materials were the three principles. Many of the claimed features of Prairie houses were in fact associated with these principles. This subsection only discusses the first two principles, which are within the scope of this thesis. Simplicity (unity) and plasticity (continuity) can be interpreted as two facets of the same concept. Continuity can be interpreted as the lack of abrupt separation between two entities, which in turn helps their perception as connected elements of an integrated whole (unity).

In regard to the layout of Prairie houses, the literature review suggests that the concept of simplicity (unity) was reflected in the interlocking blocks whose composition was unified by a central fireplace. Furthermore, the unit and grid systems of the house implied the use of a singular integrated system of construction. The idea of unity in physical form was further endorsed by the continuity of elements. The latter ideal is usually considered present in the covered but open spaces such as terraces and porches of the Prairie houses, which sit between the fully enclosed interior and fully open outdoors. This type of space is common in Prairie houses compared to nineteenth century houses. The horizontal stance of the house and the layers of terraces were also taken as symbols of its unity with and continuation of the prairie site.

Considering the spatial features of the Prairie houses, the principle of unity or simplicity is supposedly reflected by the more holistically-perceived space and the open plan. While the supposed reason for this holism (open plan) is supported by visual evidence in the literature, the claim that space is perceived as a whole (in comparison to Victorian houses), is mainly based on the conjecture that an open plan will lead to a holistic perception, or on the personal assessment of the authors.

Another aspect to unity is the focal position of the fireplace as the symbol of integrity of the family life. This focus relates to different aspects from symbolic, to structural, aesthetic, and visual focus. The physical evidence is indeed adequate to verify the different design of the fireplace in the Prairie style; however, it is not clear how significant the topological (visual) role of the fireplace is in the houses compared to other elements. Laseau and Tice (1992) offer one of the few studies which approached the significance of fireplace systematically, however, their focus is mostly on the relationship between the fireplace and living room.

The "open plan" design is also a manifestation of the ideal of continuity (or plasticity). There is an approximate definition for continuity as the lack of abrupt separation between two entities, mainly the voids (rooms and interior-exterior) and the reducing the isolation of rooms (that also exists in the idea of simplicity). Visually, it is easier to directly observe this definition as it is more concrete than "perception". Another demonstration of the continuity is considered the intrusion of material from exterior façade to interior wall and vice versa, a visible characteristic that is also rare in Victorian houses. However, again when it comes to interior voids (rooms) continuity is reduced by the idea of corner opening and rooms "flowing" into each other (when they meet in corners). Connecting spaces from their corners rather than axial centre is suggested to have increased the visual interaction of the connected spaces. This is supposed to encourage the perception of the connected spaces as a continuum. Furthermore, it makes spaces less isolated from the rest of the house. This claim may have two facets. Firstly it describes a change in the shape of the then-common boundaries of space. This change had "broken the box" layout of the rooms which was the norm in that era. The other facet is simply based on the visual sensory effect of considering the rooms being more visually connected to each other. The literature understandably argues mainly for the former facet, but also tends to conclude the latter as a logical consequence of the former.

Both continuity and simplicity are also reflected in the supposedly increased circularity of the Prairie houses. This circulation provides more interaction for dwellers with each other. Although this claim is more qualitative (the existence of circulation rings), the sources claiming this have not provided statistical data to support it. Another claim associated with the circulation in the Prairie houses is that it encourages interaction between the members of family. This claim has parallels to the shift from being the social part of the house as the expression of gentility, to being a container and shelter of family life.

Another claimed quality of the Prairie houses is their appeal to both habitants and visitors. Unlike arguments about wholeness, this claim is supported by surveys from inhabitants in addition to qualitative speculations of scholars (Hildebrand, 1991). The reasons for its appeal are approached variously. Generally, a number of Wright's own words are considered (better scaled for humans, and more natural in shapes, colours and materials). A part of this appeal or pleasure is associated with the mentioned ideas of wholeness and continuity (e.g., the continuity works in increasing intra-family socialisation). Furthermore, the notion of "character of a house" (as shelter) is also considered as important to the perception of the house, especially when this character is reduced to its ancient minimal of hearth (as represented by the focal fireplace). Regarding this character, 13 common elements have been identified by Hildebrand (1991), most of which are present in all houses designed by Wright. He argued those may be a source for the appeal. Similarly, bridging to the environmental theory of prospect and refuge, Hildebrand asserts that Wright's houses have the basics of the intrinsic satisfaction demonstrated by that theory (that also includes the "shelter" character of the house). This idea is limitedly supported by the quantitative case studies of Dawes and Ostwald (2013a, 2014b) using properties of isovists.

While the dissimilarities between the spatial features of the Prairie and Victorian houses are often emphasised by the literature, there are also similarities between them. One of the main similarities is the segregation of the three main zones of the houses (private, service, and social). Regarding the first floor, the service and social zones are still separated visually and spatially based on the same logic in the Victorian houses (the odour and mess of the service zone). While this similarity is mentioned in the literature, the extent of it is not elaborated.

In summary, several spatial features of the Prairie houses have not yet been objectively assessed. Instead scholars have based their conclusions on assumptions of a causal relationship between the directly-observable (physical form) and non-observable features (topology) – a process which we call *conjecture,* borrowing from Gero (1996). For at least one of these aspects, spatial configuration, the excellence of those principles has been a recurring theme in the literature since the time of Wright. Table 2.2 shows the claimed spatial features of the Prairie houses and the way these claims are supported in the literature. In this table, the focus is only on the claims about the topological features of the Prairie houses are listed, thus, it disregards claims solely pertained to physical forms.

Table 2.2. A summary of studies on the topological features of the Prairie houses.

Claimed/studied features	Method/studies	Study
Holistic interior spaces	comp.[1] conj.[2] (based on corner openings)	Wright (1960) *reflected in:* Giedion (1962)Twombly (1979) Maddex (2000, 2002)
Open space / visually more connected spaces	comp. conj. (based on corner openings)	*same as above, and* Brooks (1979)
Character (shelter/refuge)	comp. conj. (as it is more "human")	*same as above, and Twombly (1975)*
	prospect & refuge (formal, but lacking comparable scale)	Hildebrand (1991)
	computational evaluation of the former (using isovist)	Dawes and Ostwald (2013a, 2014)
Emphasised fireplace	comp. v.o.	Wright (1960)
Increased social interaction in interior spaces	comp. conj. (based on centrality of the hall and "more" rings passing the living room)	Twombly (1975, 1979) Maddex (2002)
Simplicity of spatial programme (minimal spaces)	comp. v.o.[3] (comparing with the nominal Victorian houses)	Wright (1960) *reflected also in later studies.*
Continuity of spatial perception in interior spaces	comp. conj. (based on corner opening and "open space")	Wright (1960) *reflected also in later studies.* Twombly (1979) Maddex (2002)
Desirability and undesirability of certain spatial connections	v.o.	*mainly for Victorian houses (Cromley, 1996), implied by* Wright (1960) *about Prairie houses.*

[1]. comparison between Prairie and Victorian houses
[2]. conjecture based on visual observation or similar
[3]. visual observation

2.6. Conclusion and discussion

This chapter has outlined a summary of the characteristics of Prairie houses as claimed or demonstrated in the literature. The Prairie style emerged after the Victorian era in the Midwest United States. While it is often considered a revolutionary style, it shared a significant number of values and theoretical background with late Victorian society. However, these values had not yet materialised in the architecture of that era.

It has been discussed that Wright had a number of ideal features and principles in mind which he tried to implement into his Prairie houses. The characteristics of the Prairie houses are supposed to reflect these features and principles. As presented in the previous section (2.5.2), the majority of the literature has approached them through qualitative methods. While there are quantitative studies (e.g., Koning & Eizenberg, 1981; Chan 1992) on the shapes and forms of the Prairie houses, such studies on spatial (topology) are scarce and not necessarily focused on the Prairie houses (e.g., Hildebrand, 1991, and following scholars) but on all Wright's designs. In other terms, our understanding of the spatial features of the Prairie houses is not reviewed under the potentiality of many newer quantitative methods. This includes both the relationship between the Prairie houses and their Victorian predecessors, and the intrinsic characteristics of the Prairie houses.

In this regard, the studies differ in the type of cases they selected, as mentioned in the introduction of this chapter. A number of them, particularly the older studies, had a comparative approach by which they identified properties of Prairie houses by contrasting them to Victorian architecture. These studies also discuss the shift from the Victorian to Prairie architecture. Regardless, a main area of focus is how the Prairie style heralded several innovative design features in domestic architecture, a focus that makes sense considering the reputation of the style as the first genuinely modern style or as a rejection of classic styles. These innovative features more or less reflect or repeat a number of principles stated by Wright. These studies discuss a large number of aspects of design ranging from forms, to materials, to spatial organisation of the houses. Most of the comparative studies and the identification of features are based on the direct observation of the differences, as found in the building documentation or photos. While these observations are more or less reliable, they have become the basis of assumptions about some properties which are not otherwise directly observable. This literature review also identified spatial configuration as the main type of the latter properties. However, there is an empirical model that supports the causal relationship that the mentioned studies have considered between the directly observed features and the spatial features alleged because of those directly observed features.

However, other studies focused on Prairie houses (or specifically Wright's houses) to identify or measure their properties without comparing them to earlier or later designs. These studies focus on how Prairie houses resemble or differ from each other, rather than how they differ from another style. There are more recent studies in this approach, which have had the opportunity to use more formal and empirical data and models for conducting their methodology. However, save the notable but topically limited exception of Hildebrand's (1991) prospect and refuge approach (and its space syntax extensions) the spatial configuration of Prairie houses and their relationship with the architectural elements of the houses have remained unaddressed.

In summary, there are two gaps in the literature. First, the existing literature on the spatial or topological features of Prairie houses is not satisfactory as it is largely confined to qualitative research which either may not be reliable or is not extensive enough to be accepted as representing the spatial properties of the entire style. Secondly, this lack of quantitative analysis prevails for both Prairie houses and their relationship with Victorian houses. These two research gaps are the catalyst for the present research, as explained in Chapter 4 (research design and methodology). This gap requires using a quantitative method of analysis. The next chapter discusses the theory of space syntax, which is widely applied for the quantitative study of architectural space and its topology.

3. Space syntax theory

3.1. Introduction

This chapter discusses the theory of space syntax, a framework for quantitative analysis of spatial features. Aspects of this method are adopted for the present dissertation.

Understanding human behaviour within a built environment has been a regular topic of debate in architectural scholarship, especially since the rise of modern movements (Lang, 1987). Considering the subjectivity of this topic, researchers have tried to develop objective – and in many cases numerical – representations of different aspects of the perception and behaviour of people in the built environment. The subject of this chapter is the theory of space syntax, a quantitative theory aimed at explaining social patterns of behaviour in regard to movement through and visual interaction with space.

The chapter is organised into five sections (in addition to this introduction). The first section (3.2) reviews the development of space syntax theory and its basics and terminology in graph theory. It is followed by a section (3.3) discussing the techniques of space syntax theory, including their variants, purpose, and applications. The next section (3.4) discusses the contexts and research areas where space syntax is used. Section 3.5 outlines the limitations of space syntax and finally, Section 3.6 summarises the reviews and findings of this chapter.

3.2. Background and definition of space syntax

During the last century, the relationship between architecture and human behaviour was studied through various channels. A similarity between these studies was the desire to identify patterns of correlation between architectural features and the human's perceptions of and reactions to them. One of the earliest of these approaches came from Gestalt psychology, focusing on perception and aesthetics of forms and shapes and their absence (voids). Gestalt psychology considers a number of visual properties of components (for example, similarity and symmetry) that influence understanding of the whole (Behrens, 1998).

From the late 1950s and onwards, another branch of psychology – cognitive sciences – came into focus. The difference between perception-based Gestalt and cognition was that the latter put more emphasis on memory and learning ability (Sternberg, 1996). Cognitive theories also discuss the importance of components and their relationships in understanding a whole. Taking the urban space as this whole, an influential theory by Lynch (1960) suggested that space is understood by making a cognitive map in the mind which is made of number of components (paths, districts, edges, nodes, landmarks), and their connections to each other (again paths). In other terms, the mind creates a graph representation of the space in order to "cognise" it. An important feature of Lynch's approach (and similar graph-based approaches) was the tendency to explain the continuous and concrete space by discrete elements (of the graph).

The decades of the 1960s and 1970s furthered the understanding of space using objective and empirically-supported frameworks. A number of theories and models emerged from the study of territorial behaviours of animals (including humans). In that research, space was defined as a mixture of risks and opportunities, realised by distance, movability, control, and supervision. Altman (1975) considered that the behaviour of people changes according to zones based on distance (namely, public, social, private, and intimate). Appleton (1975) in his theory of *Prospect and Refuge* demonstrated that having an unimpeded vista (prospect) while being able to hide or protect presence (refuge) would create an intrinsic pleasant feeling in humans as well as having been crucially important for the survival of the species. In the mid-1970s, Newman (1996) proposed the idea of *defensibility* of a space based on the properties of being seen (or supervised) and accessed, as well as the sense of belonging to space. In a parallel study, Alexander, Ishikawa and Silverstein (1977) provided a number of *patterns* which captured working architectural settings across different cultures which partially demonstrated the tenets of the mentioned theories. In these examples, space was explained partly or wholly by the mathematical or geometrical relationship of its elements or inhabitants. The difference between these studies and the cognitive models such as Lynch's, was that the mathematical models were more based on intrinsically hard-wired behavioural traits in humans.

Space syntax can be considered a combination of the desires behind these two trends of studying space: the discrete representation of the complex space and the objectively computable parameters, where the discrete elements are interconnected as a whole within a *syntax* (as in linguistics). The term *space syntax* can be dated back to the work of Hillier, Leaman, Stansall and Bedford (1976) and gained momentum in Hillier and Hanson's *Social logics of space* (1984). Similar to Lynch's model, space syntax theory abstracted space into a graph. However unlike the former, but similar to the territorial theories of 1970s, it used gross visuo-mobile sensory observation to devise the components of the graph, rather than semantic cognition of spatial elements. In this approach, the social meaning of the buildings is "an intrinsic aspect of their physical form" (Hillier & Hanson, 1984, p. 62). The physical form is derived from the gross parts (geometry) of the physical form, not its superficial properties such as colour or material (Bafna, 2012b). Hence, the quintessential logic of space syntax can be summarised as that people navigate through space based on where they can *see* (the property of visibility) and where they can *go* (the property of access) (Hanson, 1998), two properties which are deductible from geometry. The only spatial property which affects this navigation is the permanent boundaries in space which may hinder movement and visibility.

Based on this logic, space syntax models make graphs which represent access and visibility in different scales and different definitions of space. The simplification of the complex space into a basic non-dimensional graph made space syntax models easy to formulate.

Thus the theory of space syntax is an effort to present a syntactic and discrete computational model of space based on its permanent geometry, in the form of a graph which provides opportunities for specific interactions between the inhabitants, leading to behavioural patterns (Bafna, 2012b). Space syntax presented itself as a universal and computational basis in addition to being a theory about certain aspects of human behaviour in architectural space. In the next subsection, the fundamental concepts of this theory are discussed.

3.2.1. Definition of space syntax

The title *space syntax* collectively refers to a set of techniques for quantifying and analysing the properties of architectural and urban space (Hillier & Hanson, 1984). The current sets of techniques were developed separately in the late 1970s in works of Benedikt (1979) and Hillier et al. (1976). They were eventually joined together under the title of 'space syntax' in the 1990s. The premise which joined these different techniques together was the idea of abstracting space into graphs. Space is often described as a continuous and concrete three-dimensional entity (Franz & Wiener, 2008). However, in order to analyse architectural space, space syntax methods typically convert or abstract some aspects of the spatial configuration into a syntactic and discrete model (Bafna 2003). Hillier (2007, p. 303) compares this idea to the physics' concept of inertia – continuous and straight movement (or lack of movement) of an object until it is affected by a force. The discrete model of space thus stands for the patterns of movement (of people and information) through the space as affected by the elements which break its straight continuity. As part of the process, space syntax privileges the topological properties of a space over its geography, in order to record the movement patterns because people tend to behave (i.e. move) in ways that are based on topology (Ostwald, 2011a). As a result, a space syntax approach uses graph theory because it provides the perfect basis for analysing topological relationships. This is the reason space syntax abstracts architectural space into graphs.

The author has summarised the abstraction of spaces into graphs in four steps (Behbahani, Gu & Ostwald, 2014) which are explained below:

1. Reducing the space to its geometrical features.
2. Defining the usable portion of space (i.e. defining the boundaries of space).
3. Abstracting the usable space into nodes of a graph.
4. Making the graph by connecting the nodes.

a) Reducing the space to its geometrical features

Considering the primary movement of people is horizontal, the geometrical reduction of space is usually the same as using the two-dimensional floor plan. However, there are a few studies that also use sections as well as using multi-storey floor plans, but their usage is limited both to only one technique of space syntax (*convex mapping,* see 3.3.1) and also by the amount of existing literature. More recently there have been efforts to apply space syntax theory to 3D settings (Bhatia, Chalup & Ostwald 2012; Suleiman, Joliveau & Favier, 2012; Lazaridou 2013). These efforts are also limited to one technique of space syntax (*visibility grid analysis,* see 3.3.3). In addition, 3D space syntax is still in its infancy. Hence, in this section, we only discuss the usage of floor plans for space syntax models.

b) Defining the usable portion of space

Space syntax theory is largely concerned with the permanent boundaries of the space that are typically equivalent to all non-movable vertical partitions (i.e. walls, fences, etc.) in addition to doors which separate indoors and outdoors (as for buildings) (Ostwald, 2011a). Additional boundaries such as changes in ceiling height or floor level (i.e. stairs) can also be considered boundaries which separate two internal parts of a space (Peponis & Bellal, 2003). Among them, the staircase falls between a vertical partition and level change, and so, usually up to a certain height (eye height) it is included inside the boundaries. On the other hand, doors are usually considered non-permanent or movable and so do not hinder the movement. The only exception is usually the entrance door(s) which indicates the border between indoors and outdoors. However, depending on the authorisation of access, other doors may also be considered as non-movable and thus, permanent. An example of this distinction for boundaries can be seen in Haq's (2003) case study of hospitals, where some doors were not supposed to be opened by patients or visitors.

Depending on the purpose of the analysis, a space separated by a door may be excluded. For example, Dawes and Ostwald (2011) argue for the exclusion of spaces that are without a "social" activity (such as store rooms) or are too small to be inhabited (such as service risers).

c) Abstracting the usable space into nodes of graph

After the definition of geometry and boundaries, the space is represented by a graph. Graphs are dimensionless in their simplest form. Therefore, converting a 2D floor plan into such a graph requires further geometrical abstraction of the plan. Returning to the idea of dividing space into discrete components as the core of space syntax analysis, the techniques of space syntax differ on how they define the components of space or the 2D floor plan. Dimension-wise, there are three possibilities of compartmentalising a 2D entity, which are dividing the 2D area into one or more 2D areas, representing features of the space by 1D lines, and dividing the space into dimensionless points. These three forms of abstraction are more or less identifiable with the three approaches of space syntax, namely, *convex mapping* (dividing space into 2D areas), *axial mapping* (representing space using 1D lines), and *isovist mapping* (articulating space in a grid of dimensionless points) (Klarqvist, 1992). These approaches are explained in Section 3.3.

d) Making the graph by connecting the nodes.

A connection between nodes is defined based on the level of abstraction into nodes and the abstracted element. Connections are usually a simple binary parameter of the existence of a connection. In the simplest form, for 2D areas, a connection may mean sharing a side, while for 1D lines, it is their intersection which defines the connection. For dimensionless points, the possibility of drawing a line segment between them is represented by the simplest definition of the graph connection.

3.2.2. Graphs and their terminology

As mentioned, space syntax theory is essentially based on graph theory. This foundation is so crucial that studies done based on mere graph theory, without using explicit space syntax techniques, are sometimes passed as space syntax studies as well. Graph theory is a domain of mathematics which concerns the definition, measurement, and analysis of the graphs. A graph is a diagrammatic system of representation of sets and connections between them (Bondy & Murty, 1982). This subsection discusses some definitions and measurements in graph theory which are fundamental to all space syntax measurements. The content of this subsection is a free interpretation of Bondy and Murty (1982), Biggs, Lloyds and Wilson (1998), and Diestel (2000) (the main difference between these sources in the context of the topic of this thesis is in terminology).

a) Nodes and edges

A graph (commonly represented by letter G) is a structure for representing the connections between a number of items. In graph terminology, the items are called *vertices* or *nodes* (here we use “node” onwards to avoid confusion with geometrical vertices, although they will be represented by letter V) and their connections are called *edges* or *arcs* (we will use “edge” in this thesis hereafter). The amount of (total) number of nodes is usually shown by k. In its basic form, a node is an abstract, dimensionless entity without any features, probably except for a reference to the real object or person it represents. The edges also represent only the Boolean state of connection, which is defined according the context.

Both nodes and edges can be attributed with different properties which can be used in further measurements. For example, in a spatial context, they can have geometrical features such as coordinates, size, angle, direction, etc.

b) Connectivity and neighbourhood

The nodes which are directly connected to another node are called *neighbours* of this node, while their number indicates the *connectivity* value of the node.

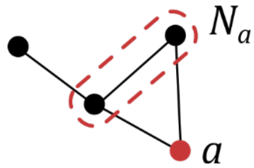


Figure 3.1. Neighbourhood (N_a) of the node a.

c) Path

The connection between nodes may enable navigation inside the graph from one node to another. If such navigation is possible, there is one or more *paths* between those two nodes. Paths are found by *pathfinding* algorithms.

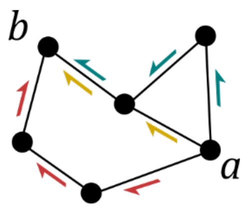


Figure 3.2. Different paths from node a to node b.

d) Shapes of the path

Graphs are usually too abstract and flexible to have geometric shapes. However, they may have attributes which resemble shapes. The two most important shapes are *trees* and *cycles* (Figure 3.3). A tree is a graph configuration in which it is not possible to start navigating from a node and then be able to return to that node without passing an edge twice. In contrast, it is possible to return to that node in a cycle. In space syntax, the cycles are also called *rings* (as in Hillier & Hanson, 1984; Hanson 1998).

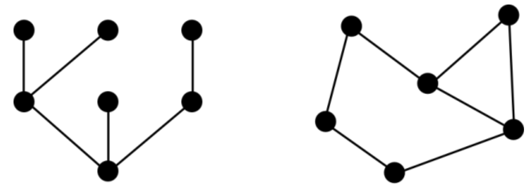


Figure 3.3. Graphs with shapes of tree (a) and cycle (b)

e) Depth and distance

Paths, like real paths, represent the distance between two points (nodes), although in a graph the definition of distance varies based on the graph properties used in pathfinding. In basic graphs, distance is defined as the number of edges passed to reach from one node to another. When there are paths between two nodes, one or more of them is the *shortest path* depending on how distance is defined. The distance represented by the shortest path is called the *depth* between those nodes, and is measured by the number of edges on the path. For example, in Figure 3.2 , the yellow path is the shortest between *a* and *b*, with the depth of 2.

f) Local, global, and holistic measures

The measures of connectivity and depth are considered local as they only measure the relationship between a partial number of nodes of the graph. On the other hand, there are measures which represent a feature concerning all of the nodes in the graph. Usually, the global measures are calculated by a collective operation on local measures. One example is *mean depth* (MD), that is, the average of the depth values from a node to all other nodes of the graph. MD value indicates the degree by which a node is integrated into a graph compared to other nodes of that graph. Global measures such as MD only indicate the properties of a single node, but on a global scale. To understand the whole of a graph, there should be measures which represent all nodes at once. One example is the average of MD values for all nodes (though it does not demonstrate any quality in existing space syntax literature). In this thesis, this type of measure is termed *holistic*.

3.2.3. Measures of space syntax

While space syntax is based on graph theory, it has added measures regarding the context of architecture and urban design. Below are a number of frequently used measures in space syntax analysis.

a) Relative asymmetry and integration

While mean depth (MD) value represents the degree of integration of a node with other nodes, it is not directly comparable across different graphs because the total number of nodes vary between them. Therefore, another set of measures are considered to allow comparability between graphs (Hillier & Hanson, 1984). The first of them, *relative asymmetry* (RA), is a proportion of MD and the number of nodes (k) as shown in Equation 3.1.

(3.1)

$$RA = \frac{2MD - 1}{k - 2}$$

(Hillier and Hanson, 1984)

However, it is the reciprocal of RA, called *integration* (i), which is mainly used in space syntax analysis. The measure of integration indicates the degree by which movement through a space (or visibility towards it in case of visual measures) is natural to its functional setting (Hillier, 2007) or in simpler terms, the likelihood of a space being accessed or visited.

RA and i values have been demonstrated to be still incomparable between graphs with drastically different k values. Therefore, Hillier and Hanson (1984) proposed a normalisation coefficient (*d-value* or D) based on an ideal binary diamond-shape graph that is calculated by Equation 3.2 (presented in Kruger & Vieira, 2012). The product of RA and d-value is termed *real* relative asymmetry (RRA), whose reciprocal makes the integration value i.

(3.2)

$$D_k = 2 \times \left(\frac{\mathrm{k}(\log_2 \frac{k+2}{3} - 1) + 1}{(k-1)(k-2)} \right)$$

(Kruger and Vieira, 2012)

b) Control value

While the connectivity value indicates the size of the neighbourhood of a node, it does not indicate the significance of the node in its neighbourhood. Amongst the local values concerning immediate neighbourhood, *control value* (CV) is frequently used in space syntax studies. CV indicates the degree by which a node controls the access to its neighbours (Ostwald, 2011a). The word "control" means the portion of access to a space. For example, if a room is accessed by two separate corridors, each corridor has half control over the access to that room. For any node V_i, the value CV_i is calculated by Equation 3.3 (where *N* indicates the number of neighbours).

(3.3)

$$CV_i = \sum_{j=1}^{N_i} \frac{1}{N_j}$$

(adopted from Ostwald, 2011a)

c) Choice

The control value (CV) only measures the significance of a node for the access to its neighbours; it does not measure whether that node is crucial to the access to the neighbour. To measure such significance for the whole of the graph, there are other measures which indicate the mediation of a node on the path between all nodes in the graph. In other terms, these measures represent the number (or a ratio) of times a node is located on the shortest path between nodes of the graph. In graph terminology, such measures are usually associated with *centrality*. However, in space syntax, it is usually called *choice.*

d) ***Intelligibility***

Space syntax provides a few holistic measures for analysing graphs. One of the frequently used of them is *intelligibility* (hereafter as *I*), that is the Pearson correlation (*r*) between the local measure of connectivity and the global measure of integration (*i*) through all nodes of the graph (Hillier, Hanson & Graham, 1987). Intelligibility could be regarded as revealing the clarity of a spatial organisation for a person inside the space (Ostwald, 2011a).

3.3. Techniques of space syntax

In space syntax theory there are three approaches to abstracting space into nodes regarding the dimension of abstraction. The spaces would be abstracted to 2D, 1D, or dimensionless entities which respectively are articulated into maps called convex, axial, and isovist maps. In this section, these three mapping approaches are discussed.

3.3.1. Convex mapping

The definition of architectural space has traditionally had a strong association with the idea of visual enclosure. In space syntax, this idea is mainly captured by the definition of a *convex* space, an area in the shape of a convex polygon in which all points are mutually visible to each other (Hillier & Hanson, 1984). In this method, space is divided into a number of convex spaces, which are the largest, "fattest", and fewest in number. While largest (in area) and fewest are taken literally, there is no robust definition of fatness (Batty & Rana, 2004). Nevertheless, a common interpretation of fatness is the compactness of space (the ratio between the area and perimeter of the convex boundary) (Batty & Rana, 2004). Alternative interpretations have been proposed (e.g. medial axis skeleton by Miranda Carranza and Koch, 2013) for drawing convex maps. Due to the "fat" nature of the shapes of the convex map, this approach is best suitable for defined spaces such as building interiors in contrast to narrow and long streets in urban spaces (Miranda Carranza & Koch, 2013).

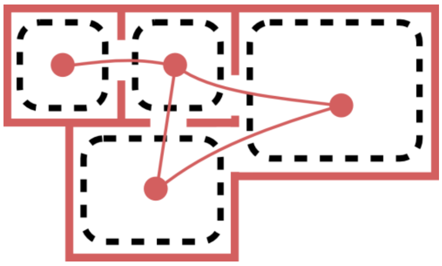


Figure 3.4. The convex spaces and their corresponding graph

The convex spaces in the map are translated into the nodes of a graph while their connections are typically converted into the edges of a graph. The connection is usually defined as a property of both adjacency and permeability, that is, the availability of direct access (by way of a door or opening) between two spaces (Peponis & Wineman, 2003). These spaces and their connection are collectively termed a *convex map* (Klarqvist, 1993).

This method of convex mapping is the most commonly used approach to devising the graph. However, differentiations in floor level or ceiling height may also be treated the same way as the vertical boundaries such as walls (Peponis & Wineman, 2003). In any case, there are many convex spaces ignored because if their insignificance, mainly due to their relatively small size (e.g., door thresholds). On the other hand, some researchers tend to extend the idea of insignificance to lack of "social functions". They use social boundaries, including the social activity or "function" of the room, instead of geometry (convexity) to define a spatial entity (Bafna, 2012a). In this case, a fat L-shape or T-shape living room may be considered as one space despite consisting of two convex polygons.

a) Properties of convex map graphs

The nodes of convex map graphs are dimensionless representing a convex area. They usually do not have any extra property (such as weight or coordinates), although it is possible to assign labels to them for usages unrelated to space syntax (as in Eloy in 2012, where the labels are used as descriptions for shape grammar). The connection between the nodes of the graph usually represents the binary property of access or permeability between two nodes (spaces). This is probably due to the high level of abstraction (from 2D area to dimensionless node) that renders the graph devoid of geographic and proportional properties. Accordingly, the convex map graphs are also termed *adjacency graphs*. However, convex mapping is rarely used for representing visual relationships between spaces. Few studies, such as Eloy (2012), have limited defined connections as the binary state of mutual visibility between two spaces, though no further calculation is provided.

Adjacency graphs are commonly illustrated based on their *carrier,* that is the node representing a selected base space (according to the purpose of measurements). Hence, the graph is drawn like a tree grown from the carrier node. Other nodes are placed (or "justified") in ordered levels according to their respective syntactic distance from the carrier (Figure 3.5). This approach to the adjacency graph is known as *justified plan graph* (JPG).

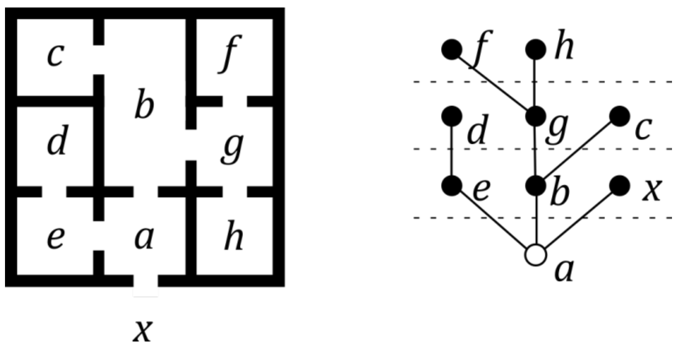


Figure 3.5. Justified plan graph for space a.

b) Measured properties in adjacency graphs

Adjacency graphs are primarily used to investigate the configurational relationships between rooms in a building (Ostwald, 2011b). They provide a measure for the arrangement of architectural programmes relative to how spaces are used (Bafna, 2003). Regarding their high level of abstraction to dimensionless graphs, they are usually not useful for assessing visual relationships in the space.

The measures of MD, CV and *i* are frequently used for adjacency graphs. These measures are used to obtain the least and most integrated spaces (or generally, the order of spaces in regard to integration) in a building. The results may be compared to other buildings or different settings of the same building. For the latter comparison, an example is Hanson's (1998) comparison between the *i* values in graphs with and without the inclusion of "outside" space. This comparison supposedly reveals whether (and how much) a space is interacting with outside or inside the building. Given the spaces usually correspond with conventional concept "room", and that the room is usually associated with a number of social functions, the measures of adjacency graphs are useful for analysing the functional configuration of buildings.

There are two ways of comparing the numerical results of convex maps such as integration or RA values. In the first way, the actual numerical results are used and compared together. In the second way, the numbers are represented by their ordinal ranking (Hillier, Hanson & Graham, 1987). The latter makes it easier to both draw an organisational hierarchy of spaces and compare results and identify the order of spaces within different graphs. In space syntax terminology, the ordinal ranking is usually called a *genotype* (or its derived words) especially when it holds for multiple cases (Hanson, 1998; Hillier, 2007).

c) Limitations of convex maps

The graph of a convex map presents a dimensionless topology devoid of geographic and proportional properties. Because of this, adjacency graphs fall short in several areas. First, they are not efficient for capturing visual relationships between spaces. Secondly, they have a static approach to space (as points) which neglects the movement and paths within the space. Finally, because of the abstraction of the convex area to a single node in the graph, the precise mapping of this space to the node is not clear (Dawes & Ostwald, 2013b).

3.3.2. Axial mapping

People orientate themselves by what they see and where they can go (Hanson, 1998). This can be represented on a plan by a straight line without any visual or access interruption that indicates how far a person can see or go in a direction. In space syntax terminology this vector is called an *axial line* (Klarqvist, 1993). An axial line through a point in space is the longest line within the space boundaries that includes this point (Turner, Penn & Hillier, 2005). It is notable that a boundary includes whatever impedes access, disregarding the visibility through the boundary.

A common algorithm for producing a map of such lines is called the *all-line* approach. It draws all of the possible lines passing through or to all vertices of the boundary (Turner, Penn & Hillier, 2005). The all-line axial map is not used directly for any calculation, but it is first reduced to a *fewest-lines* map. The fewest-lines map consists of a minimum number of axial lines which are the fewest and longest lines together covering or passing through every convex space in the floor plan (Ostwald & Dawes, 2011a) using certain algorithms (Peponis, Wineman, Rashid, Hong-Kim, & Bafna, 1997; Turner, Penn & Hillier, 2005). An alternative method (Batty, 2004) detects the fewest lines based on measures of isovist analysis (see 3.3.3) although this method is not often used. In space syntax terminology, the total layout of the fewest lines is called an *axial map* (Klarqvist, 1993).

The geometry of intersecting lines provides different possibilities for defining the components of the graph depending on whether the line is considered as a connector. In general, there are three variants of axial mapping, namely primal, segment, and dual. They are explained here.

a) Primal axial map and graph

In the earliest studies on axial mapping, the lines comprise the nodes of the graph and their intersections, as the Boolean state of connection, are represented by the edges of the graph (Hillier & Hanson, 1984). The intersection as the edge variation represents the turning point in the line of sight while navigating the space. This approach to graph development is described as a primal approach (Batty, 2004) wherein the axial lines represent the likely paths of movement. In regard to their geometrical properties, these maps may be more suitable for representing long and narrow urban spaces (i.e. streets) and are frequently used for analysing such spaces (Bafna, 2003).

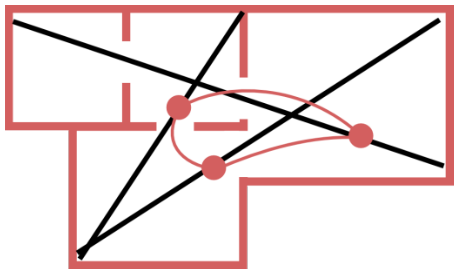


Figure 3.6. The primal axial lines and their graph

The primal axial graphs also capture some behavioural characteristics of the spatial settings, and show the ideal paths of movement within a (Bafna, 2003; Ostwald & Dawes, 2011a). The axial lines can also be used to detect important vistas. Similar to adjacency graphs, CV and *i* are the most commonly measured values for axial maps. The integration value (*i*) usually suggests the degree of "walk-ability" of a path in the space, as well as its importance in decision-making in movement.

The primal axial map is limited in several aspects. The space is abstracted so intensively that many geographic properties of space are neglected, especially in geometrically-distinct building spaces. A small change in the boundaries may significantly (and incomparably) change the axial lines. Furthermore, the lines do not refer to a clear location in the space, but a range of locations (Dawes & Ostwald 2013b).

b) Segment map

In a primal axial map, the intersection of lines does not have any effect on the definition of the lines, but on their connection. An axial line can have intersections with multiple other lines in different points. However, in an alternative definition, the intersection of lines is considered as a point where the intersecting lines break into two segments. Therefore, a segment is never crossed by another segment but only meets the other at one of its ends.

Segments comprise the nodes of the graph, while their connections (joined at their ends) are represented by the edges (Turner, 2007). The segment maps are ideal for design settings such as streets in which the spaces are so narrow and long that the axial lines are more or less aligned with the spaces. In this case, the axial lines are also drawn without a convex-based algorithm, but by using the rectitude of the streets. Therefore, each segment or node of the graph represents a (straight) segment of street. On the other hand, they are not suitable for representing "fat" spaces such as building interiors.

Segments can accurately represent geographical properties (the coordinates of the endpoints, their width and length). Thus, they allow having a range of weighted measurements of depth and MD such as the degree of turns (angle) (Turner, 2001a; Hillier & Iida, 2005). Accordingly, the angular depth is measured by summing the angle of turn on the segments' intersections in a path between two points. The smallest angle sum will indicate the shortest path. For more clarity, Turner (2001a) also suggests a definition of *a turn* as an angle sum of 90° degrees.

c. Dual axial map graph

Batty (2004) formalised an inverted version of the primal fewest lines graph, which he termed a *dual* compared to the original primal axial mapping. In this variation, the intersections of the axial lines are represented by the nodes of the graph, while the edges of the graph represent the segments of axial lines which attach the intersections. The dual axial mapping has the properties of the primal axial map graph as the line layout remains the same. However, the nodes (intersections) in this approach actually represent a precise spot in the space.

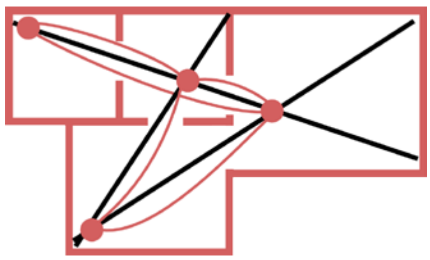


Figure 3.7. The dual axial map and graph.

Dual axial graphs have the capability to represent the properties of certain spots of the space. These spots are taken as representative of the visually important points of the space in regard to visual surveillance and decision-making. Common space syntax measures such as MD and *i* are used to identify the most visually significant spots in the space.

Dual axial graphs are only rarely used for analysing building interiors, although this may be because they are not well understood (Dawes & Ostwald, 2013b). In addition, unlike all other approaches to making graphs, there is no commonly-used software for making dual axial maps. One issue of using them in building interiors is that the intersections do not necessarily cover all (convex) spaces in the building, and so some information may be lost. To resolve this issue, Dawes and Ostwald (2013b), following Peponis et al. (1997), proposed a method to consider the end of certain axial lines as nodes of the graph.

3.3.3. Isovist mapping

Each point in space has a unique geometrical relationship with its surroundings which gives it unique visual properties. In a floor plan, a unique property of each point is the area visible and accessible from that point, in the shape of a polygon; this is called an isovist (Benedikt, 1979). Due to the impracticality of considering all points, the space is typically articulated into a fine grid (ideally in the size of a human), and isovists of each cell on the grid are drawn. A graph (called a visibility graph) is then developed with the cells as its nodes and the existence of visibility between cells as its edges (Turner, Doxa, O'Sullivan & Penn, 2001). This visibility graph has a low level of abstraction because every node represents an actual point in space. Therefore, the nodes can possess detailed geometrical properties such as position and isovist characteristics.

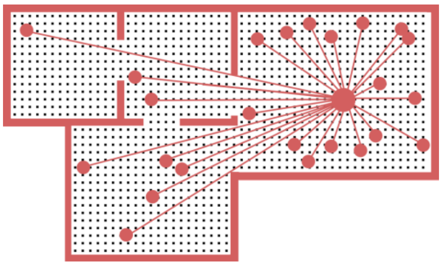


Figure 3.8. The grid articulation of space and a schematic representation of visibility graph.

Visibility graph analysis (VGA) reveals the properties of the points in space. These properties include mean depth, enclosure, compactness (Franz & Wiener, 2008) and trans-visibility and visual control (Ostwald & Dawes, 2013). The visibility graph is essentially derived from a 2D collection of points or, in other words, a defined area. It is therefore suited to spaces with fat areas and clear boundaries such as building interiors (Ostwald & Dawes, 2013).

a) Measured properties

Isovist graphs are the least abstract graph among space syntax techniques, and therefore the nodes retain various ranges of geographic properties such as precise size and coordinates. Similar to axial maps, it is possible to consider either the step or angular definition of shortest path. However unlike the axial maps, the MD values are available to all points of the space. The MD values are calculated by two methods of syntactic (or step) and angular shortest paths. The syntactic shortest path (resulting in step depth) is a path with the lowest number of straight lines necessary to move from one point to another. The minimum value for a step depth is 1 (i.e. connection to a directly visible point). On the other hand, the angular shortest path (resulting in angular depth) is a path with the lowest amount of turns (in degrees). The minimum value for angular depth is zero (direct visibility). Based on Turner's (2001a) suggestion, a sum of 90 degrees is defined as a *turn* in visibility graph analysis.

In addition, connectivity value can also be defined as the area or percentage of space visible from each node, as nodes represent a measurable area of the space. However, due to the large number of nodes and edges, the global measures such as integration and intelligibility are not as useful as in other two approaches.

Conversely, there are other geography-style measures useful in isovist maps. *Through vision* indicates the number of times a point in the space mediates the direct visual connection between two other points. A higher through vision indicates the centrality of the point in the spaces. It is a local version of *choice* measure which itself can be measured for both angular and step depths.

Apart from the graph-based measures, isovist maps offer a number of pure geometrical measures regarding each isovist. There are basic properties such as perimeter and area. The latter is more or less the same as connectivity but in a different measurement unit. Derived by them, there are measures to indicate concavity of the isovist. It is calculated by dividing the square of isovist perimeter by its area as *roundness* (Franz & Wiener, 2008). An alternative calculation for a similar concept of *circularity* was proposed by Benedikt (1979) with considering a 4π in the denominator of the roundness' fraction.

3.4. The applications and contributions of space syntax

Space syntax theory has been used for a variety of purposes. Three aspects of application of space syntax techniques are considered for this research. One aspect is the position of space syntax in the methodological framework of a research. The second aspect concerns the topics covered by space syntax techniques. Finally, the third aspect is the outcomes of space syntax studies. The next three subsections discuss these aspects respectively.

3.4.1. The methodological position of space syntax

Space syntax techniques are a collection of mathematical techniques which are unified through a certain ontological view of the social meaning of space.

- *As the tested hypothesis*: there is a clear difference between what space syntax techniques measure (behaviour) and the nature of their results (number). There have also been critical responses to the high level of abstraction in the method. Hence, a question of some space syntax studies is whether the technique or approach of space syntax is efficient to address the measured parameters. In this case, the usefulness of the space syntax technique is only hypothetical, and it needs to be checked against empirical data (usually *in situ* observations of crowd behaviour). This approach is usually adopted to investigate fundamentally new techniques or interpretations. It is also used for reviewing the usefulness of an existing technique.
- *For measuring*: once the usefulness of a technique is tested, studies implement it to evaluate the spatial features of a building or urban design. This is probably the most common usage, as the space syntax theory has been already established. The goal of this approach is to explore the topological features of the measured cases.
- *For testing a hypothesis*: this third approach has some features of both previous approaches. Like the first approach, two sets of data compared to each other. However, similar to the second approach, space syntax may be given priority to test and verify the other (as a hypothesis). In a strong scenario, the space syntax technique approves or rejects the hypothesis, while in a weaker scenario, only part of the hypothesis would be found addressable by the technique.

Disregarding the specific approach, the next section reviews a number of topics addressed by space syntax.

3.4.2. Topic of space syntax studies

In general, there is a broad common objective for space syntax techniques – to model the interpretation of space in order to capture its structure and effects on users' motion and orientation. However, there is an obvious difference, as explained earlier, between access, motion, and visibility, which are the main foci of convex, axial, and isovist mappings, respectively. This difference contributes to various usages of space syntax techniques. An aspect of this difference is the dual nature of access, movement, and visibility. The dual nature can be represented by the prepositions *to* and *from* (e.g., access *to* and access *from*) or in the contrasting concepts of permeability and privacy. These two concepts are discussed here.

a) Navigation and wayfinding

The theory of space syntax is based on the notion that human understanding of "the social meaning of environment derives from its spatial organisation" (Ortega-Andeane, Jimenez-Rosas, Mercado-Domenech, & Estrada-Rodriguez, 2005, p. 13). People orientate themselves by what they see and where they can go (Hanson, 1998). Therefore, an extensive part of the space syntax literature is about orientation within space.

An important focus of orientation is on the wayfinding inside a building or urban complex (Ortega-Andeane et al., 2005). Particularly for buildings, wayfinding is crucial for the functional efficiency of the building, especially when it serves a relative large crowd. Public buildings such as commercial buildings (Brown, 1999; Fong, 2003), libraries (Zook & Bafna, 2012), museums (Hillier & Tzortzi, 2006) and hospitals (Haq, 2003) have been subject to case studies using space syntax methods. Nevertheless, isovist mapping was mainly introduced from a study (Benedikt, 1979) on navigation in terminal buildings. In exhibition and commercial buildings, the property of navigability is usually a positive characteristic for a space or a part of it. Space syntax techniques provide a number of means to investigate this property. For example the integration value of convex mapping reveals a degree of accessibility, or the access aspect of navigation; the choice value of convex or axial mapping identifies the likelier spaces to be passed through; mean depths of isovist maps reveal the likelihood of being visible and so being visited.

A portion of studies on wayfinding focus on emergency situations such as evacuation (e.g., Ünlü, Ülken & Edgü, 2005) because in such cases perception-based flock behaviour may take priority over cognitive familiarity with space (Turner & Penn, 2002). This situation makes space syntax more suitable for analysing the efficiency of a design for facilitating emergency evacuation. Finally, a number of studies have focused on the relationship between space syntax premises and the development of cognitive maps of the urban space (Meilinger, Franz & Bülthoff, 2009).

b) Permeability and privacy

While the capacity of being visited or accessed is important for the success of some spaces, the opposite would be true for other spaces. In other terms, different activities require different degrees of being exposed to other spaces or people. This applies also to the related concepts such as supervision and privacy. In this sense, space syntax techniques are used to understand the spatial organisation of buildings or urban spaces.

The integration (or similar depth-related) values are being used to study the relationship between the topological and functional characteristics of spaces. In urban scale, there are several studies (e.g., use of an urban plaza by Bada and Guney, 2009) which focus on the flow of traffic (pedestrian or motorised) and its relation or correspondence with the topological map of the streets. Usually, axial mapping is used for this purpose. In smaller scales, a number of studies have used space syntax analysis to identify relationships between criminal activities and spatial configurations (Nubani & Wineman, 2005), regarding the importance of permeability on the defensibility of a space (Newman, 1996).

Space syntax techniques, especially convex and isovist mappings, are also used for the organisational aspects of buildings. It is common to compare the results of space syntax measurements with the activities associated with the spaces in the buildings. Residential buildings have been one of the earliest subjects of space syntax studies (Hillier & Hanson, 1984; Hanson, 1998). A relevant example to the topic of the thesis is a case study of functional sectors of houses of different pre-modern and modern styles in northeast Brazil with convex mapping (Amorim, 1999, 2001).

The results, whether actual or ordinal values, are used to draw a hierarchical map of spaces that can be used for both understanding and predicting how a building works. Ultimately, such studies can be used to understand the lifestyle of the occupants of the building (Hanson, 1998).

3.4.3. Outcomes of space syntax studies

The previous subsection outlined a number of contexts in which the space syntax techniques contribute to the understanding of the architectural space. The understanding of spatial organisation is thus the main outcome of space syntax techniques. This subsection discusses two additional outcomes and usages of the space syntax theory.

a) Comparative analysis

Space syntax is a powerful tool for comparing spatial systems (of buildings or urban design) with each other. This comparison can be based on any of the techniques and for any of the previously mentioned purposes. The main goal of such comparisons is usually to understand similarities and differences between the studied cases, and identify patterns and regularities in a group of designs (Hanna, 2006; Dalton & Kirsan, 2008). The cases of a comparative space syntax study may be two (or more) instances or a collection of buildings. Architectural styles are one of the areas in which such comparisons are applied, in order to understand the topological features of them (e.g., in Hanson, 1998; Orhun, Hillier, & Hanson, 1995; Dawes & Ostwald, 2014). In this case, space syntax techniques are used to identify recurring topological structures in style or design trend, which is called *genotype* (or *genotypical tendencies*) (Hillier, Hanson & Graham, 1987; Bafna, 2012a). Genotypical tendencies are the consistency in the order of the integration values of spaces in a number of buildings which represent a common topological structure of those buildings (Bafna, 2012a). For example, using genotypical inequalities Bafna (2001) identifies organisational differences between houses designed by Mies van de Rohe and a representative set of contemporary houses.

b) Decision-making

While all of the previously mentioned applications of space syntax are for post-design analysis (i.e. analysing an existing design), there are also studies which focus on the use of space syntax during or prior to design. For example, Eloy (2012) has used the logics of convex maps to control a certain part of the design grammar for rehabilitation of residential buildings in Lisbon. Grasl and Economou (2010) incorporated graph theory to control their shape grammar of Palladian villas. Lee, Gu, and Ostwald (2013) and Lee, Ostwald, and Gu (2015) proposed using space-syntax-based graph grammar for evolving new instances of Glenn Murcutt's houses.

Despite this, the usage of space syntax for generative purposes is still limited to a handful of studies. A reason for this limitation may be the drastic changes in space syntax measures after a small change in the design, which makes the connection between design decisions and their topological consequences harder to predict. Nevertheless, the combined approaches to space syntax and the design process is considered to be a more recent approach compared to the rest of literature, and so, it is still an unexplored and promising area.

Generally, disregarding the purpose for which space syntax theory is used, it is regarded as an objective method for measuring certain spatial qualities. Designers prefer to have a handy quantitative evaluation for a spatial configuration in order to understand how it encapsulates function and usage (Franz & Wiener, 2008). Space syntax provides a credible measurement from the viewpoint of the user instead of the designer's bird's-eye view (Turner et al., 2001). It can be regarded as a justified method without which the designers tend to use their personal experience in order to estimate the performance of a space (Dursun, 2007).

3.5. Limitations of space syntax

Due to the focus of space syntax on gross visibility and movement, it is limited in several regards. The limitations are generally related to the abstraction of spaces and computation of measures. Considering the abstraction, space syntax reduces the space into abstract topological features based on solely permanent geometrical boundaries in a two-dimensional plane. Therefore, it lacks many other properties of space unrelated to geometry, or if related, not permanent (such as furniture).

Space syntax theory also abstracts human understanding of space into visual sensory and motor functions, disregarding human cognitive abilities. This undermines the efficiency of some space syntax measures when people are familiar with the space in question..

One of the strong points of the theory of space syntax as a method is its formal and objective approach to analysing spaces. However, there is a challenge in the initial stage of the boundary definition and graph development. In the case of boundary definition, a small detail (e.g., the inclusion of a 10cm projection of a column out of a wall) may over-proportionally change the axial maps and their analysis. In VGA, the answer to the question of where the grid starts (offset from the boundaries) would change the results. In convex maps, there are minuscule spaces (door thresholds, narrow margins, etc.) often left out of the map. However, the question remains of when spaces are too small or thin to be considered invalid.

Technically, space syntax techniques are generally limited to 2D spaces thus far (though there are promising advances for 3D spaces). Some of the commonly accepted computational tools for supporting syntactical analysis still have some interface issues or takes a considerable amount of time for calculations. Furthermore, for some purposes, there is not yet a universally-accepted tool.

3.6. Summary

The theory of space syntax is a derivation from graph theory for the purpose of analysing topological features of built environment. The theory is founded on the idea that people understand and navigate through the space partially based on the visibility and access to parts of the space. In this regard, the theory abstracts space initially to the crude geometry which hinders visibility or access. In the next step, it further abstracts the geometry by representing it with graphs which provides a platform for mathematical analysis of the space. While these abstractions mitigate the complexity of space and facilitate the quantification of topological qualities, they also limit the applicability of space syntax because many other aspects of space and its occupants are neglected in this theory.

Techniques of space syntax theory are used in different research scenarios. One scenario is to investigate the understandings reached through other research methods such as qualitative research. Another scenario is to analyse the space for the sake of discovering spatial features. Regarding the research gap (the lack of quantitative understanding of Prairie spaces and the claims about them), both of these approaches show relevance in this research. The next chapter discusses the methodology and research design for this thesis.

4. Research Design and Methodology

4.1. Introduction

This chapter discusses the research design and methodology for this thesis. The first section (4.2) explains the two stages of the study required to achieve the overall outcome and the remaining sections propose the methodology applied to these stages. The second section (4.3) explains the selection and preparation of cases for the research. Section 4.4 explains the space syntax techniques and measures applied to the cases. This section is followed by the discussion of the computational tools used in this research for space syntax measurements. The fifth section explains the logic, expectation, and verification methods of analysing the results. This section is crucial to understanding the visualisation and terminology in the following chapters. Finally, Section 4.7 explains the limitations faced in this research.

4.2. Research design

The literature review on the Prairie houses (Chapter 2) has suggested that there is a lack of quantitative research on the topological spatial properties of Prairie houses. While there are a number of topological features identified for those houses, only a very few have been studied through a rigorous quantitative method. In addition, most of the existing qualitative studies were written before the 1970s, a time since when most of the scientific models of architectural space have been developed. Therefore, the existing studies lack the thorough examination necessary for identifying spatial features of the Prairie house. Many of the notable studies after 1970 (e.g., Twombly, 1979; Laseaux & Teal, 1992; Maddex, 2000, 2002) also used a qualitative method to approach the topological features of the buildings. The majority of the contribution of these studies is about the form, material, and construction of the houses.

Nevertheless, in all studies the Prairie houses have been approached in their historic context, that is, mostly in comparison with the existing residential architecture of middle to late 1800s (the Victorian era) in the United States. A number of studies (e.g., Chan, 1992, Laseau & Tice, 1992; Pinnell, 2005) have focused on the features of the Prairie style *per se* (especially, in comparison of the houses with each other), disregarding earlier architectural styles. Hence, there are two main approaches posed to study the Prairie houses : a comparative study focusing on comparing the Prairie houses with the Victorian houses in order to investigate similarities and differences; and a study (also often comparative) between the Prairie houses to identify and investigate differences and similarities between a set of houses of the Prairie style.

The overall aim of this research is to enhance the understanding of the Prairie houses by providing a quantitative analysis of their spatial properties. Regarding these approaches, the aim of this thesis has two respective parts, these being:

1. To understand the differences and similarities between Victorian and Prairie houses (including examining claims made in the literature). This initial aim is approached by using space syntax techniques to methodologically identify the spatio-topological characteristics of Prairie houses in comparison with the mainstream design convention of the Victorian era. In addition to identifying the spatial properties, this stage also reveals the possible effects of layout variation on the topological settings considering that the layouts of Victorian and Prairie house are significantly different (see 2.2 and 2.3)
2. To understand the differences and similarities between Prairie houses themselves. This secondary aim of the research involves a comparison between Prairie houses in order to identify regularities between their

design features (i.e. layout and other architectural shape elements) and their spatio-topological settings.

In the following subsections, the outline of the two stages of the research are explained.

4.2.1. Stage I: comparing Victorian and Prairie houses

The first stage of the research focuses on the comparison between the Victorian and Prairie houses. This stage commences with an investigation of the claims about the topological features of the Prairie houses which are already mentioned in the literature (2.5.2). The research then tries to identify previously-overlooked features in the Prairie by comparing them to Victorian houses of the era. The selection of the cases, the application of measurements, and their analysis are explained in the following sections.

For the first step, a hypothesis is devised out of each claimed spatial feature for the Prairie houses. The hypotheses are tested against the results of relevant space syntax measurements (as explained in 4.4). These hypotheses are described in respective sections of Chapter 5. In addition to investigating whether the featured claims are supported by the application of space syntax theory, this section of the research aims to develop new understandings of the differences or similarities between the spatial features of the Prairie and Victorian design conventions (especially if the hypotheses do not return positive results.).

For the second step in this stage, the cases (of both styles) are compared using alternative aspects of the results of the first approach or by other techniques of space syntax. Contrary to the first step, there is generally no existing hypothesis available for the measurements of this approach. The results for each measure are then compared to find if there is a significant difference between the two styles. This approach to the first stage aims to identify differences between spatial features of the Victorian and Prairie houses and to outline innovations or contributions of the Prairie residential style which were previously overlooked in the earlier studies.

An additional analysis technique derived from this methodology allows for a process for categorising, or ranking the Prairie houses in terms of embodiment of the style. Thus the results for the first steps were used to identify Prairie houses which fit the most or least in the descriptions of the Prairie style in the literature, and also the houses which are closest to the average of results for the Prairie houses. For this purpose, in each measurement, the first two or three houses were identified featuring what is deemed (by literature) or found (by analysis) to be exclusive or innovative properties of Prairie houses. Following all measurements, the results were revisited to see whether there are houses which represent the Prairie style more or less. Three denominators are considered for this purpose including "Prairie-like" (featuring positive departure from Victorian houses), "Victorian-like" (featuring more similarity to average or distinctive Victorian house) and "representative" (closest to the numerical average of the Prairie houses in a measure).

Figure 4.1 illustrates the two approaches of the first stage of the research. It should be noted that this stage of the research regards the Prairie houses collectively, assuming they are more similar spatially to each other than to Victorian houses (as a collectively similar cluster). This may be a limitation of the first stage of the research as there may be Victorian houses which are more "advanced" spatially and Prairie houses which are less "advanced" compared to the rest of the Prairie corpus. This limitation is one of the reasons for a more thorough study of the Prairie houses (Stage II).

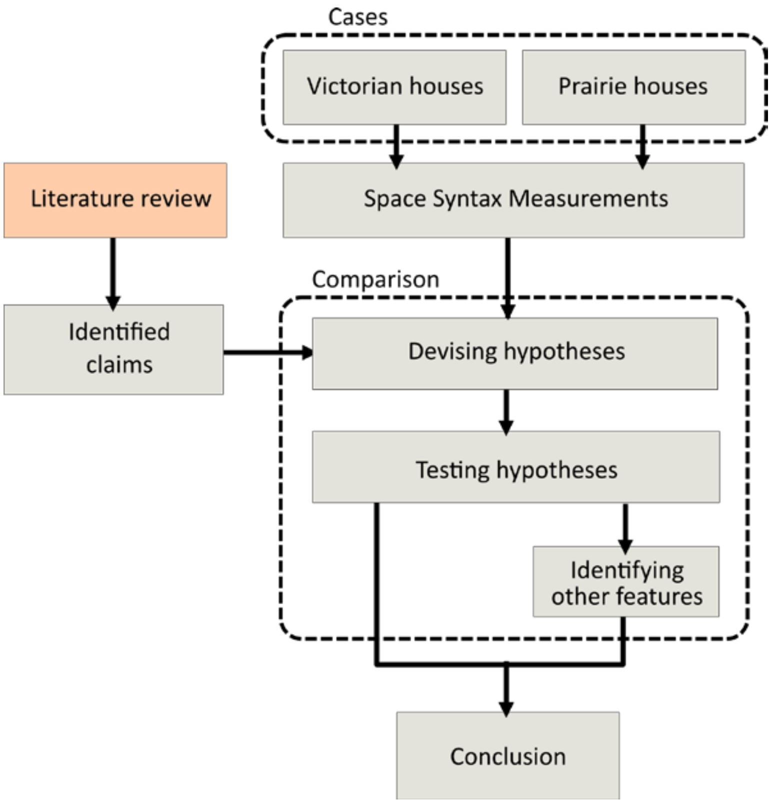


Figure 4.1. The diagram of Stage I of the research.

4.2.2. Stage II: Analysing Prairie houses

The second stage of this research focuses on the spatial and layout features of Prairie houses. In this stage, Prairie houses were categorised based on their layout features for which the spatial measures are analysed. The main expectation from Stage II is to identify patterns or regularities between the layout and spatial features of Prairie houses. For this purpose, for each space syntax measure a set of hypotheses were provided based on the layout of each category (there may be more than one categorisation for each measurement) in order to provide a foundation for the comparison between the Prairie houses. The hypotheses were checked against the results and their validity is considered as a correlation between the layout category and the measured spatial feature. The detailed objectives of this stage are:

1. To identify possibly overlooked layout features which could be helpful for understanding spatial features.
2. To identify the possible correlation between the layout features and the spatial properties of Prairie houses. This includes understanding

what layout features may have more influence on certain spatial features.

3. To provide a new understanding of Prairie style houses in regard to their spatial settings.

Figure 4.2 shows the procedure of Stage II. As seen in this figure, this stage does not contain any additional space syntax calculations or measurements to those of the Stage I. This stage uses the same results as the previous stage, but with different statistical approaches (i.e. clustering them into layout-based categories).

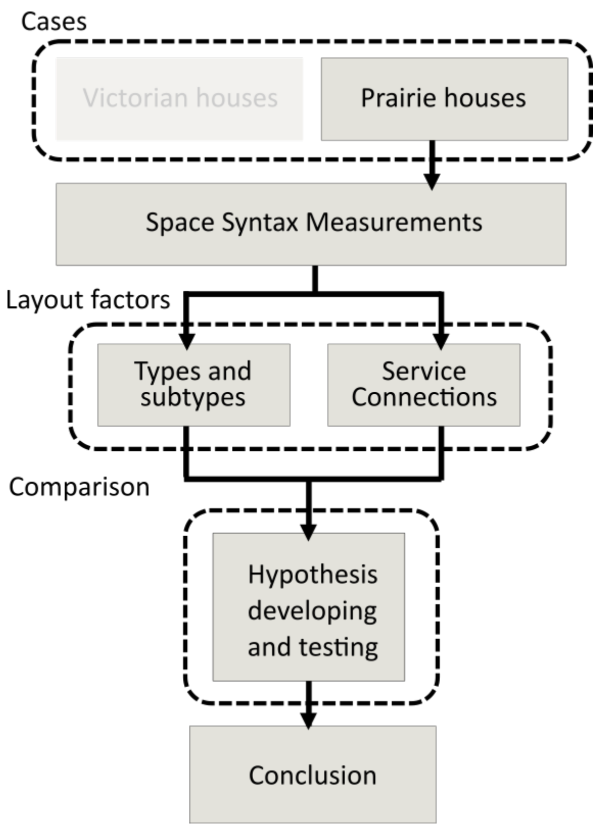


Figure 4.2. The diagram of Stage II of the research.

It should be noted that there is another possible approach to layouts by identifying them through space syntax measures (e.g., Dalton & Kirsan, 2008). In this case, the results of the measurements are statistically clustered and then their corresponding layouts are compared to find regularities. This thesis did not opt for this approach because it would have needed to focus on and verify two sets of interdependent data (layouts and spatial measures versus literature claims) which might not have been feasible in its time frame. Additionally, a main theme of the study is to examine the existing literature which includes the selected layout (Pinnell's).

Both stages of the research are essentially reliant on case studies. The first case study (Stage I, both parts) is comparative, between selected Victorian and Prairie houses. The second case study (Stage II) is also comparative but between the houses within the Prairie style.

Both stages of the research are also significantly focused on the mathematic measurements and comparison of spatial features. Therefore, the research is predominantly quantitative. The rest of this chapter pertains to different aspects of the quantitative characteristics of this research including measured spatial properties (4.4), the mathematics and tools of their measurements (4.4 and 4.5), and the comparison between results (4.6).

Nevertheless, there is also a qualitative aspect in this research. Most importantly, the identification of influential layout-based features was conducted based on visual observation (though based on the numerical results). Furthermore, considering the indecisiveness of space syntax measures and the variable nature of architectural space, further quantitative discussion is unavoidable when interpreting and explaining the results.

4.3. Selection and preparation of cases

Both research stages involve case studies of Victorian and/or Prairie houses. In this section, the case study approach is explained. This includes the criteria for selecting cases, introducing the selected cases, and preparing the cases for measurements.

4.3.1. Selection criteria

The goal of the case selection process is to identify Victorian and Prairie houses which are suitable for this research. Considering the analogous nature of the first stage of the research, the main criteria of suitability is the *comparability* of cases. The comparability of houses is defined here as reducing the number of factors affecting the topological aspects of the houses to a minimum. This reduction, of course, does not include the layout properties, as they are the other subject of the comparison. However it includes the scale and "functional" programme of the houses. This section discusses the criteria of selecting the cases.

As explained in the literature review (Chapter 2), both Victorian and Prairie houses feature a relatively standard spatial programme. In late Victorian and Prairie houses they were informally called "foursquare" because their layout consists of four square-shaped (or "fat" rectangle) functional zones. Accordingly, each "square" represents a certain functional zone. This four-square type is approached differently in each style. For Victorian houses, this example is often a fat rectangular layout which is internally divided into four rectangles forming a 2x2 grid, where each cell of the grid is occupied by a square. In contrast, an ideal representative of Prairie style would be a cruciform layout where squares are located in the respective wings. Although these layouts examples are not strictly followed in the majority of houses, the abstract notion of four main functional zones are the focus in the literature. This implies that the research cases should follow these layout criteria.

Another important feature of the foursquare house is the location of the functional zones in the first level of the house. Three of the squares are always service zone (kitchen), dining room, and parlour (which was refashioned as living room in Prairie houses). The fourth square can vary significantly between houses. Two common spaces are library and entry-hall. The latter is usually combined in the Victorian houses where the hall occupies most of this square's area. On the other hand, the Prairie entry is often emphasised enough that it stand separately as a square. In this thesis, the houses with an entry-hall square are selected mainly because of the available typologies in the literature.

In Section 2.4.1 (parts b and c), two detailed typologies of Prairie houses by Chan (1992) and Pinnell (2005) were introduced. Pinnell's typology considered only houses with an entry square, while in Chan's typology, four of the six types feature houses with an entry square, and the two others have a library replacing the entry square. Chan's types are limited to houses with a central fireplace while Pinnell additionally considered side fireplaces. In other terms, the only difference between types in Pinnell's typology are between features of layout (placement of elements and spaces) while Chan considered spatial programme as well. Hence, Chan's typology does not fulfil the minimalistic condition of comparability, as explained in the beginning of this section.

Another feature compared in this study is the time of the design and the architects. The Victorian and Prairie styles are diverse both in terms of time and designers. Regarding the designer, the focus of the study is on Frank Lloyd Wright as the main innovator and the subject of claims in the literature. Therefore, only the houses designed by him will be considered from that group. On the other hand, since the goal of this study is to compare Prairie style to the architecture of the Victorian era, the Victorian cases are not bound to particular designers, in order to include a more general concept of Victorian design. In contrast, the *time* for Victorian architecture plays a more important role. In order to exclude possible influence of Wright's ideas on contemporary Victorian house design, the case study considers only houses designed before 1893 (the beginning of Wright's independent career and the construction of Winslow and Oak Park houses). Additionally, the Victorian houses should not have been built long before 1893, because of possible socio-cultural differences in their functionality. In summary, the selection criteria are as follows:

- Simpler layouts (only four squares).
- Simpler functional programme (service zone, parlour, dining room, and entry).

- Simple service zones (at most one additional space to the base service functions).
- Prairie houses are designed by Frank Lloyd Wright.
- Victorian houses should belong to the time before 1893 but not more than two decades earlier.

In addition, only the first level interior of the houses was considered. The second level (and basement) was excluded for the following reasons:

- While the second level (and in some cases basement) is part of the spatial system of both Victorian and Prairie houses, it is the first level that has always been the focus of the literature (including the discussed claims) regarding both visual and programmatic configurations.
- Adding the private zone (with a considerable number of spaces) to the convex mapping would have significantly changed the measurements to possibly a point where a meaningful understanding about the first level was not feasible.
- Technically, it would have not been feasible to perform a visual analysis between the two stories (as both VGA and axial mapping are mainly 2D). Therefore, it would not have been possible to compare the outcomes of convex mapping measures and VGA measures.
- While considering open and semi-open spaces (porches) in convex mapping would have contributed to the understanding of an overall configuration of the house, they would have significantly affected the VGA and axial mapping of the interior in a negative way. Therefore, the study is limited to interiors in order to maintain the comparability of results across the mappings.

By applying the above criteria, 15 Victorian houses documented by Cirker (1996), which were built between 1885 and 1893, and originally collated and published in *Scientific American* (Architects and Builders Edition), were selected. The chosen house plans are: untitled cottage (Plate 2); Cottage at

Monmouth Beach (Plate 5); Cottage at Block Island (Plate 8); $1800 Dwelling (Plate 9); Swiss Cottage at West New Brighton (Plate 10); $1200 Cottage (Plate 18); Dwelling for $2500 (Plate 25); Dwelling of Moderate Cost (Plate 27); Dwelling of Moderate Cost (Plate 40); Residence on Long Island (Plate 43); Residence at Mount Vernon (Plate 49); Residence at Bridgeport (Plate 52); Suburban Dwelling (Plate 55); Cottage at New Rochelle (Plate 60); Residence at Edgewater (Plate 75). Many of these designs, if not all, were "pattern-book" houses which, like "project" or "tract" houses, were repeated with variations for different clients in different locations in northern and north-eastern USA. The floor plans of these houses are presented in Appendix's section I.1.

For the Prairie style, 27 houses were selected for analysis including (by year):Little (1902), Martin (1902), Robert (1902), Ross (1902), Walser (1903), Adams (1905), Baldwin (1905), Barnes (1905), schemes #2 and #3 for Sutton (1905), the "$5000 house plan" (1906), DeRhodes (1906), Brown (second scheme, 1906), Nicholas (1906), Fuller (1906), Millard (1906), Little (1908), May (1908), Stockton (1908), Baker (1909), Gale (1909), Larwill (1909), Waller (1909), Ziegler (1910), two schemes for Adams (1912), and Kellogg (1913). The floor plans for these houses are adopted from Futagawa (1987a; 1987b). The floor plans of the selected Prairie houses are presented in Appendix's section I.2.

4.3.2. Preparation of the cases:

The preparation of cases includes three steps:

- Scanning the printed floor plans and digitalising them in CAD software.
- Defining the abstracted (or measurable) portion of the plan to use in space syntax software.
- Distinguishing and labelling major spaces.

For the first step, all 42 plans were scanned and then manually traced using AutoCAD software. There were two possible limitations in the process of tracing the walls. First, a few of the Prairie floor plans had low contrast or smudged graphics which might have affected understanding the actual thickness of the walls. Nevertheless, the possible error will not be significant. Another problem is related to the spaces under staircases, particularly in Victorian houses. This issue comes from the way floor plans were drafted in the late 1800s. In some floor plans the staircases are fully drawn even above the eye line so that it is not clear whether there is a space under it or not. In these cases, it was decided that even if there was a space under them, it would have probably been a socially insignificant space (e.g., a closet).

The AutoCAD plans were exported as DXF files (R12 version) and imported into different applications including depthmapX software (Varoudis, 2014) and DAG and Viraph, both devised by the author (see 4.5.2 and 4.5.3) where the main space syntax measurements were undertaken.

For the second step, the measurable portion of the houses is defined by considering permanent boundaries which blocked access (e.g., internal and external walls, in addition to main entrance doors which separate the indoors and outdoors). As is mentioned in 3.2.1, the theory of space syntax bases its measurements on the permanent boundaries. Vertically, the measurable portion was also limited to about 160cm in height – the height of the average human eye line. This height was considered to be about eight to nine steps based on the scaled sections of the Prairie houses. The same height was also used for the Victorian houses, as no sections were available for them. In cases with two levels of staircase, the priority of eight-steps is given to the upward stairs. Although this could be regarded as a limitation of the thesis, the resulting error would be insignificant compared to the scale of the house. In addition, a social boundary was considered by excluding from the analysis non-habitable spaces, including closets, coal stores, and ice-houses. Similarly, the unidentified space under staircases was also excluded.

While there are approximately 11 spaces in an average Victorian or Prairie house, only a handful of them are consistent and functionally so important to be analysed in this study. Therefore, most of the measures were applied for a certain selection of spaces which are called *major spaces* hereafter. The major spaces include the spaces which are considered crucial for understanding the Prairie style (and Victorian design). Naturally, the four squares (living and dining rooms, kitchen and entry) are among the major spaces. Furthermore, hall and pantry were also included. The hall is important in the Prairie house because of its usual central position and organisational role. Similarly, the hall may also comprise a square in the Victorian house. The pantry is crucial for buffering between the service and social areas of the house and so holds a similar organisation and visual importance as the hall. These six spaces (living and dining rooms, kitchen, hall, entry and pantry) are the major spaces which are subjected to most measurements in this research.

A crucial issue in regard to the six major spaces is identifying them on the floor plans, which is the third step in preparing the cases. The living room, dining room, and kitchen are easily identifiable both for their clear labelling and their associated functions and elements. However, the other three spaces require further attention in identification:

- The pantry is normally a buffer space between the service zone and the dining room. However, not all such spaces are labelled as pantries and not all labelled pantries are a buffer zone. Nevertheless, there is no single case amongst both styles in which there is both a non-buffering pantry and a buffering non-pantry. So, in the cases with absent "pantry" label, it was decided to list all buffering spaces between the dining room and the service zone as pantries as well.
- For the hall and entry, there are both labelling and location issues. In the selected Victorian houses, the hall is always labelled as such if it exists in the house. However, in the Prairie houses there are central hall-like spaces which are not labelled and non-central labelled halls (that may include a "reception hall" as well). In Victorian houses, the hall is sometimes directly connected to the exterior, making it the entrance as well. However, considering its size and labelling it is

treated here as the hall. This combination of hall and entry also exists in Prairie houses. However, neither the labelling nor the functionality and size gives a clear indication about its name. To address this issue, the priority was given to the hall (similar to Victorian houses) except in cases where it looks isolated (i.e. it has two or less connections with other spaces in the house). In these cases, the space was considered as entry.

Another important issue regarding these spaces is the convexity of their boundaries. In some houses one or more of the spaces are not totally convex and as much as 10% of their area is not part the largest convex boundary in the house. While this will not be an important issue in convex mapping, it will result in problems in isovist-based analysis. This factor results in an error margin of 10% in some of the cases if the results for the "social" aspect of the room are interpreted literally. Nevertheless, because most of rooms analysed are encapsulated into a single convex space, or have a negligible out-convex portion, its impact on the comparative outcome is not significant.

4.3.3. Categories of the Prairie layouts

As mentioned in 4.2.2, the focus of the second stage of this study is on the differentiations of Prairie layouts and spatial properties. One of the factors of the variation in the Prairie layouts is the geographical placement of the "squares" of the house. As explained in the previous subsection, Pinnell's (2005) typology was selected to represent this factor. However another factor – the connection between the service and social zones – is also considered in this thesis. In this subsection more discussion is provided for these two layout factors.

a) Pinnell's subtypes

Pinnell's typology and the reason for selecting it have already been explained in sections 2.4.1 and 4.2.2 respectively. Thus, here only the list of the selected houses featuring the subtypes is provided. Table 4.1 and Figure 4.3 show the distribution of cases among the subtypes. There are 18 houses of Type I and

9 houses of Type II. As for subtypes of Type I, there are 8 cases of IA1, 2 cases of IA2, 3 cases of IB1 and 5 cases of IB2. For Type II, there are 6 cases of IIA and 3 of IIB.

Table 4.1. The distribution of selected houses among the subtypes of Prairie houses.

Types	**Subtypes**		**Label**	**Houses**
I	A	1	IA1	House for $5,000
				Adams
				Baker
				Gale
				Nicholas
				Roberts
				Stockman
				Ziegler
		2	IA2	Adams scheme #1
				Waller
	B	1	IB1	Baldwin
				Fuller
				Little
		2	IB2	Adams scheme #2
				Barnes
				Brown
				DeRhodes
				Walser
II	A		IIA	Sutton scheme #3
				Kellogg
				Larwill
				Little scheme 1908
				Ross
				Sutton scheme #2
	B		IIB	Martin
				Meter-May
				Millard

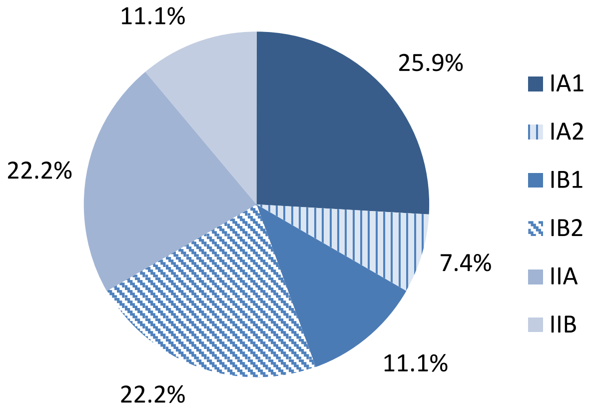


Figure 4.3. Distribution of the selected Prairie houses among types.

b) Service connections

The measures of space syntax reveal the organisation of spaces. As explained in 4.3.2, the spaces are defined by their social boundaries, not the purely geometrical convex shapes. Social boundaries are usually defined by doors or other forms of openings, which conventionally indicate the change of the "function" of the room. In this case, the space syntax measures are mainly defined based on only the labelled spaces and the connections between them. In the literature review (2.2.2) a number of favourable and unfavourable connections are identified in Victorian and Prairie houses. The favourable connections are between the social spaces of the house (dining and living rooms and hall) and the food axis (dining room to service zone). However, the connection between the clean (living room) and unclean (service zone) zones are deemed undesirable. This does not mean that such connections are not present in Prairie houses. The presence of a connection between a social space and the service zone (we will call it *service connection* from this point on) would be crucial in the definition of the spatial organisation of Prairie houses. At the very least a service connection increases the connectivity of the service zone, especially the kitchen, and reduces the syntactic distance between the kitchen and social spaces, or in other terms, it is an important factor in the formation of the convex map of the houses. Therefore, it is important to consider this factor in the analysis regarding topological measures.

Moreover, the existence of a service connection is also essentially a matter of the physical form of the house; a connection is an opening in the walls between two spaces. Therefore, it can also be regarded as another layout-based factor in addition to the types and subtypes of Prairie houses. Therefore, most of the analyses in Stage II also include a comparison between houses with and without the service connections. Table 4.2 shows the existence of the service connections in the selected Prairie houses.

Table 4.2. The presence of service connections in the selected Prairie houses

		Connected space to service zone		
Subtype	Houses	Entry	Living room	Hall
IA1	House for $5,000	●		●
	Adams			●
	Baker	●		
	Gale			●
	Nicholas	●		
	Roberts			●
	Stockman	●		
	Ziegler	●		
IA2	Adams scheme #1			
	Waller			
IB1	Baldwin			
	Fuller		●	
	Little			
IB2	Adams scheme #2			●
	Barnes			
	Brown			
	DeRhodes		●	
	Walser			
IIA	Sutton scheme #3	●	●	
	Kellogg	●		
	Larwill	●		●
	Little scheme 1908			
	Ross	●		
	Sutton scheme #2	●	●	●
IIB	Martin			●
	Meter-May	●		
	Millard		●	
% of service connections		38%	19%	29%

Pinnell's subtypes and service connections pertain to two different levels of layout designs. However, they are not necessarily independent of each other. Therefore, it is important to have an understanding of their relationship before analysing their results. Figure 4.4 shows the percentage of the presence of the service connections in the types and subtypes of Prairie houses. Regarding the overlapping of the two layout categories in many cases, the analysis in the results chapters (6, 7 and 8) will consider their possible mutual influence.

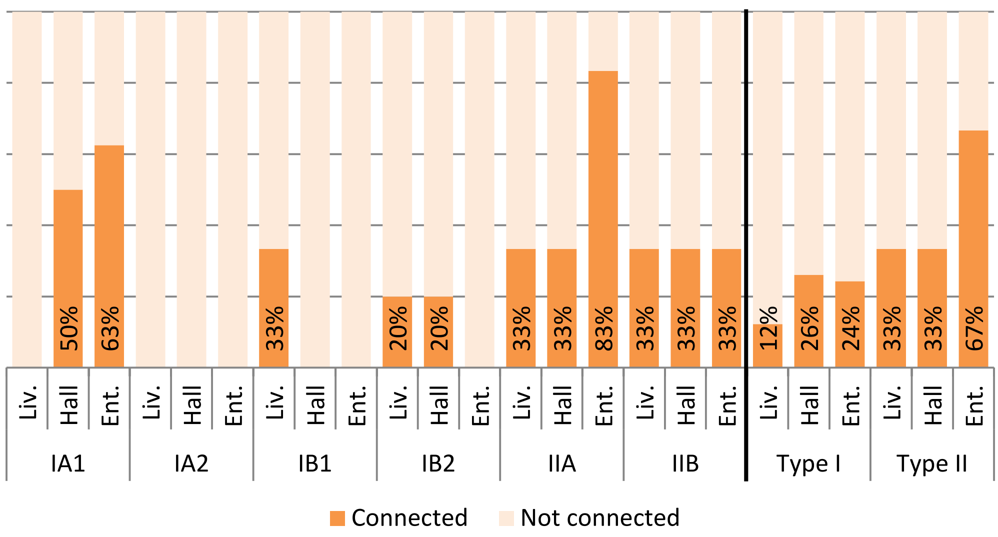


Figure 4.4. The presence of service connections with another square of the house (living room, hall and entry) in Prairie types and subtypes.

4.4. Space syntax measures

In this section, the selected space syntax measures for the case studies are explained. Considering that the basics and premise of space syntax techniques are provided in Chapter 3, this section only highlights the chosen measures and explains the way they are applied (including some modification) for the purpose of this research. In addition, based on the existing techniques, a measure (called *interspatial depth*) is proposed by the author, which is explained in more detail.

This section is structured based on the claimed features of the houses. Therefore the next six subsections (4.4.1 to 4.4.6) explain the space syntax techniques used to examine the features. However, three further sections (4.4.7 to 4.4.9) explain other techniques which are considered for additional comparisons between the two styles (the second approach of Stage I) and comparison between Prairie houses themselves (Stage II).

4.4.1. Holistic space

Wright's concept of "wholeness" is associated with the capacity to understand or communicate the properties of a larger space or form from a single visual experience of it. There are multiple complex dimensions to this concept, with some authors interpreting it as largely relating to structural expression, while others see it as an aesthetic and formal property (Hildebrand, 1991). Alternative readings of wholeness in the planning of Prairie houses also take into account a sense of the degree to which their spaces are cognitively coherent or understandable (Seligmann, 2005; Van Zanten, 2005). This more narrow and plan-based interpretation of Wrights' wholeness is similar to the space syntax concept of intelligibility.

Intelligibility (I), in space syntax terms, is the degree of correlation between local and global measures of connection that is measured by a correlation between the values of connectivity and integration (see 3.2.3).

Theoretically, four different types of intelligibility can be analysed using different spatial maps. The intelligibility of a convex map reveals its organisational clarity in terms of visually defined spaces (see 3.2.3). While it is not the primary version of intelligibility, there are several studies which have used it for interior spaces (Choi, 1999; Beck & Turkienicz, 2009; Marquart, 2011). The other mappings of a plan (primal, dual, axial, and isovist graphs) reveal its visual intelligibility, though only the intelligibility value of the primal axial map seems to have experimental support (Zhang, Chiaradia & Zhuang, 2013). For this research, both the convex and primal axial maps were adopted to examine intelligibility (I_c and I_a, respectively) as a reflection of wholeness.

While intelligibility is a combined measure of both local and global data, it is also possible to interpret the wholeness of a plan using individual global and local measures (as in Haq & Luo, 2012). The global measure of mean depth (MD) in isovist maps (or visibility graphs) reveals the degree of integration of a point in the space. Hence, the average of MD values for all points in the space may reveal an average internal integration in the space. The average value is calculated by Equation 4.1 (in which k is the total number of grid cells).

(4.1.)

$$MD_{HOLISTIC} = \frac{\sum_{i=1}^{k} MD_i}{k}$$

In this study, the MD values were measured for both angular mean depth (AMD) and step mean depth (SMD). The former is based on the minimum angular degree of turns necessary to navigate a space, while the latter is based on the number of turns. AMD is a standard feature of depthmapX's visibility graph analysis, and so the average value is automatically calculated and displayed by selecting the whole grid on the software's interface. However, the latter measure (SMD) is considered by the author for the sake of inclusiveness in respect of the visual aspect of the claims in the literature. The individual SMD values and their average were measured and recorded by Viraph software (see 4.5.2).

The third set of measures for examining the property of wholeness is the local measure of connectivity (C). In visibility graphs, this measure indicates the area of space visible from a point (in grid units, it is more or less the same as *isovist area* or IA, and so the latter term is used to prevent confusion with other usages of "connectivity"). The average of this measure reveals the area of space visible from an average point in it. The relative value of average isovist area is calculated by Equation 4.2 (where k is the number of grid units) which indicates the percentage of space visible from an average point.

(4.2)

$$IA_{HOLISTIC} = \frac{\sum_{i=1}^{k} C_i}{k^2} \%$$

The relative isovist area implies a degree of wholeness based on direct visual connection. However, it may not be the best measure to address the claim of wholeness in the Prairie houses considering the notion of "mystery" by Brooks (1975, see 2.3.5 part *b*). In this case, it is useful for comparing the houses regarding both the "mystery" claim and the wholeness based direct visual connection.

It should be noted that it is common to use the measure of "visual integration" (VI) for step depths (e.g., Guney, 2007; Abshirini & Koch, 2013). The measure was previously included in the commonly-used VGA software (UCL depthmap 10). However, a problem with this measure is its dramatic variation based on the number of grid cells (k), even after normalisation. (depthmap 10 apparently used Hillier and Hanson's (1984) d-value for this. For reasons not known the author, this measure was excluded from depthmapX (Varoudis, 2014, the latest version of the software). In other words, if the numbers of the grid cells (not their unit size) of two plans are not equal or close, the VI measure will not be useful. This is why the step MD is chosen in this study, which like AMD is not as affected by the resolution of the visibility grid.

Overall, five measures of convex intelligibility (I_c), axial intelligibility (I_a), step mean depth ($SMD_{HOLISTIC}$), angular mean depth ($AMD_{HOLISTIC}$), and average isovist area ($IA_{HOLISTIC}$) were considered to examine the claim of more holistic Prairie space.

4.4.2. Integration/isolation of spaces

Wright's definition of isolation is apparently shaped by visual factors and room areas; therefore, isovist graphs are the most useful method for assessing this (Turner & Penn, 1999). In a similar manner to the previous subsection, two measures of AMD and SMD in visibility graphs for the average points inside rooms are useful for this analysis. A related approach to this is found in the works of Guney (2007) and Hölscher and Brösamle (2009). The isolation or integration of rooms can also be interpreted as a characteristic of the direct connection between adjacent spaces. In this case, the local measure of isovist area (IA) is more useful than global measures. The average of these three measures are calculated by Equation 4.3 (X represents any of the measures and r represents the measured room). It must be repeated that the area of the room (k_r) refers to the area of the convex portion of the room, raised as an issue in 4.2.2.

(4.3)

$$X_r = \frac{\sum_{i=1}^{k_r} X_i}{k}$$

However, for buildings with only a relatively small number of spaces, the results are highly dependent on the size of the room or, in terms of grid-spacing for isovist analysis, the number of grid squares. Therefore, this measure does not necessarily reveal much about the isolation or integration of the room in the larger plan. To address this issue, the values were normalised in order to make them comparable in this thesis. The normalisation is based on removing the effect of the room's area. This differs for each of the three measures (IA, SMD, and AMD). For the isovist area, this is simply done by subtracting the room's area (k_r in grid units) from the average connectivity value of the room before dividing it by the total area of the house (Equation 4.4).

(4.4)

$$IA_r = \frac{\sum_{i=1}^{k_r}(C_i - k_r)}{k^2}\%$$

For the AMD and SMD values, the normalisation is done in two steps. The first step is to revert the mean depth (MD) values of a room back to the total depth (TD) values (Equation 4.5)

(4.5)

$$TD_r = MD_r \times k$$

The second step, however, differs for SMD and AMD. As the minimum depth is 0.0 in AMD, it means the depths between mutually visible points inside a room are all equal to 0.0 and thus, the total depth value already represents the depth to the rest of the house. Therefore, it is only necessary to divide the room's TD by the area of the rest of the house (Equation 4.6). However, the minimum value for SMD is 1.0, representing the direct connection between two mutually visible points. Therefore it is necessary to first remove the sum of these minimum values for each room and then average it by the number of grid cells in the rest of the house (Equation 4.7). The necessary figures for these equations (the room area, total area, and mean depths) are all recorded by depthmapX (for angular measures) and Viraph (for step measures).

(4.6)

$$AMD_r = \frac{TD_r}{k - k_r} = \frac{MD_r \times k}{k - k_r}$$

(4.7)

$$SMD_r = \frac{TD_r - k_r}{k - k_r} = \frac{(MD_r \times k) - k_r}{k - k_r}$$

4.4.3. Inwardness

The spatial property of inwardness can be interpreted in two ways. First, it is an indicator of a contrast between a space's relationship with other indoor and outdoor spaces. Second, it may be an indicator of the integration of spaces within the interior. Regarding the former, by comparing the integration (i) values of spaces in convex maps with and without including the exterior, it is possible to differentiate the structure of the plan in terms of relationships between inhabitants and visitors (Hanson, 1998). If the *i* value of a space significantly increases by introducing the outside space into a convex map, that space is more attuned to an outward functional relationship (between a visitor and an inhabitant) rather than inward (inhabitant-inhabitant) relationship.

Adding the exterior space to the graph affects the integration of a space for three reasons: it increases the total number of spaces, it may change the shortest paths, and it changes the total depth value for the measured space. The second reason is not possible for this study (as the exterior is only connected to one space and so cannot be on a path between two spaces). Regarding the first reason, Victorian and Prairie houses have on average the same number of spaces (11.0 and 10.8, respectively). Therefore, it is possible that the main factor for any difference between the two styles would be the third reason, which indicates how distant an entry is from a space and how it would affect the integration of that space. Nevertheless, the individual differences in the number of spaces of houses limit the certainty of the results.

For this comparison, the integration values of spaces were measured in settings with and without consideration of the exterior (only one outdoor space in front of the house's main entrance was included in this comparison). A space is considered "inward" or "outward" if the integration value of a space is significantly smaller or higher, respectively, when the exterior is included. Conversely, if there is no significant difference, the space is considered "neutral". In this thesis, a significant range is defined as a 5% difference between two integration values.

The second way to interpret "inwardness" is essentially the same as the concept of integration in convex mapping (see 3.3.1): The rooms with a higher integration value are rooms with more interaction with other spaces inside the houses. Therefore, the claim of *more socially-inward Prairie houses* may be rephrased as *more integrated social spaces* (especially the living room) or *the house being more organised around its social spaces*. In both cases of rephrasing, the organisation role of the spaces are measured by the rank of their integration values rather than their actual value. In this regard, the ranking is limited only to the major spaces in the houses.

4.4.4. Circularity

Hanson (1998) argues that there are two fundamental properties of step space in a plan: depth and rings. Rings are paths through a plan that can be taken and will eventually return a person to their starting point. Rings are considered socially advantageous or optimised, whereas hierarchical branching spatial structures are more controlling and potentially limiting from a social perspective. To compare the degree of circularity present in Prairie and Victorian house plans, the number of rings within the convex graph of each house was determined. In addition, the spaces which are included in the rings were also examined, to determine how inclusive the rings are in the two sets of houses.

In general, four aspects of rings and paths were investigated. The first aspect is the existence of a ring in the houses. The second aspect is the existence of sub-rings (a ring within another ring). Thirdly, the presence of *universal* ring, a ring which passes through all existing major spaces, was examined. Finally, there are universal paths which enable passing through all existing major spaces in the house without returning to one.

4.4.5. Desirable interactions

The literature review has identified that the service zone (especially the kitchen) of the late nineteenth century was not a desirable place because of “odours” and other “messy” features found in this zone. Therefore, there was an architectural intention to limit the interaction to not only the zone itself, but also to people associated with it (servants and maids). Evidently this regard towards the service zone continued into the early twentieth century, and thus in Prairie houses as well. This subsection outlines space syntax techniques which are suitable for analysing the issue of the service zone's interaction with the rest of the house.

Regarding the visual aspect of this interaction, measures of visual depth (step and angular depths) seem to be relevant to this topic. However, these measures are usually calculated as an average value (*angular mean depth*). This is, predominantly the depth from one point or a group of points (e.g., a room) to the *whole* of space. The importance of the one-spot mean depth is usually for visualisation (e.g., to identify the least and most visually integrated spots), while the purpose of collective AMD values are for understanding the visual properties of a portion or the whole of space (as explained in 4.4.1 and 4.4.2).

The mean depth values are obviously the average values of individual point-to-point depth. Understandably, the individual point-to-point depths are not usually a matter of research interest because there is rarely a semantic importance to the visual relationships between such minute portions of space. However, in the case of the desirable interactions, we can imagine a visual relationship between two semantically important *portions* (e.g. rooms or zones).

In theory, the visual depth between two rooms or portions of space reveals the degree of visual connection and possible flow of visual information between them. This type of visual depth will be useful to analyse the visual interaction between rooms. In this thesis, this visual depth is called *interspatial* depth hereafter. Hypothetically, it is a visual version of depth value in convex mapping. However, the problem is that despite its theoretical prominence, to the author's knowledge this measure is not explored by the literature.

To resolve this issue, the author has developed a software package, *Viraph*, to calculate the visual depths between the portions of a visibility grid (see Section 4.5.2). The formulation for this measure is simply the measurement of the average of step and angular depth values between all grid units of two portions of the visibility grid. Equation 4.8 shows the formula for calculating interspatial depth (ID) between two spaces (*a* and *b*). In this equation, V_a and V_b are points (grid units) in spaces *a* and *b* respectively, and $D(x, y)$ is the visual depth between any *x* and *y*. This equation is valid for both angular and step depths. Notwithstanding the theoretical validity of interspatial depth, the significance of this measure is not yet verified independently.

(4.8)

$$ID_{a,b} = \frac{\sum_{i=1}^{k_a}\sum_{j=1}^{k_b} D(V_{a,i}, V_{b,j})}{k_a k_b}$$

4.4.6. Focal position of the fireplace

As mentioned in Chapter 2, the Prairie fireplace is considered to have a focal (or central) status in the house. While this central position is mainly structural and symbolic, there is also a visual aspect to it (Wright, 1960; Twombly, 1979). This claim is not investigated in Stage I of the research because of the fundamental differences between the Victorian and Prairie fireplaces. In the former house type there were sometimes numerous small fireplaces within different parts of the house, while in Prairie houses there is usually only one fireplace. Therefore, the comparison between the fireplaces in the two styles would have been problematic. Considering there is only one fireplace in each Prairie house, the comparison between the visual properties of the fireplaces within the Prairie houses is possible. The fireplace is located and orientated differently within the Prairie subtypes. Therefore, its visual properties may shed light on understanding the differences and similarities between the subtypes.

The fireplace is a solid element, unlike the void elements such as convex areas, axial lines, or grid squares which are measured by space syntax techniques. Therefore, the visual property of the fireplace is in fact properties of its visible surfaces. In visibility graph analysis (VGA), it is possible to roughly represent a surface by its immediate adjacent grid cells. For the fireplace, it means to average the visual properties of grid cells around it.

However, considering that the fireplace is itself a boundary, the visual properties of the adjacent cells are considerably affected by the fireplace itself. In other terms, while the aim is to measure the properties of fireplace as one element, the fireplace may divide its surrounding cells into separate spatial entities. In this regard, the visual properties of an adjacent cell are only valid when they are calculated for the part of space which is not hindered by the fireplace. However, commonly used software such as depthmapX (Varoudis, 2014) is not capable of such a distinction between parts of space.

To address this issue, another strategy is proposed by the author. In this strategy, the fireplace is imagined to be a void space. In this case, because the fireplace is relatively small (compared to the total area of the building), there would not be a significant difference between the global visual properties of an adjacent cell and a hypothetical cell inside the fireplace. In other terms, the global visual properties of the cells inside the fireplace perimeter can roughly represent the visual properties of the fireplace itself.

For this purpose, variants of the Prairie plans were drawn by omitting the fireplace (except any part of it which borders outdoors). The new floor plans were imported into depthmapX software and the average mean angular depth of the fireplace perimeter is recorded for all houses. The results would approximately indicate the angular mean depth of the fireplace (D_f), as a singular element, to the rest of the house.

However, there is still an issue of relativity. In order to understand the visual significance of the fireplace in the house, it is necessary to compare D_f with the angular mean depth of other points in the house. Therefore, the results were compared with the most visually significant spots (minimum mean depths) in the original floor plans with the solid fireplace. If D_f is close to (or smaller than) the minimum mean depth (D_{min}) in the house, the fireplace can be considered highly integrated and so, visually significant. However, it is necessary to define the “closeness”, because the distribution of mean depth values differs in each house. Therefore the closeness of D_f and D_{min} should be scaled according to this distribution. To this end, a ratio D^* is defined to show how close D_f is to the minimum depth (D_{min}) based on its linear position between D_{min} and the average mean depth of the whole plan (D_{mean}) as shown in Equation 4.9. The lower D^* indicates the lower mean depth of the fireplace (and its high visual significance). If D^* is less than zero, it indicates the fireplace is even more visually integrated than the spots with D_{min}. On the other hand, a D^* over 1.0 (or 100%) indicates a low integrated fireplace.

(4.9)

$$D^* = \frac{D_f - D_{min}}{D_{mean} - D_{min}} \%$$

4.4.7. Other convex mapping measures

The use of two measures of convex mapping are already explained in 4.4.1 and 4.4.3 for analysing holism and inwardness of spaces, respectively. Regarding the issue of inwardness, it has been explained that a ranking of the integration values is used. In this case, the goal of that examination is only to compare the importance of social spaces between the two styles and so it does not provide a detailed analysis of the order of the integration values.

As mentioned in Section 3.3.1, the order of integration values is used by researchers to identify and compare patterns of spatial organisation which are popularly called "(inequality) genotypes" (Psarra, 2012). In this study, the orders were used to identify common "sequences" of spaces in regard to their organisational roles. Nevertheless, the same numerical results were used for this analysis and the "inwardness" comparison, so this is included in the same section as the former. The aim of this analysis is to identify further similarities or differences between Victorian and Prairie houses.

4.4.8. Other isovist mapping measures

The usage of order sequencing is not limited to convex map integration. Several studies (e.g., Clark, 2007; Nazidizaji & Saffari, 2013) have based the orders or "genotypes" on visual measures. This thesis applies the sequencing to both rooms' visual properties (average IA, SMD, and AMD) and the interspatial depth (both step and angular). Similar to the convex sequencing, the aim of this analysis is to identify regularities between Victorian and Prairie houses.

4.4.9. Axial mapping measures

Axial lines may reveal important visual axes of a building (see 3.3.2). There are different ways to analyse axial lines; primal and dual. The former focuses on the lines, while the latter emphasises their intersections. The following parts explain the application of these variants in the present thesis.

a) Primal axial mapping

There are several ways to approach axial lines depending on the context of a study. Considering the buildings and the importance of functionalist labelling of the rooms, axial lines are usually identified based on the spaces or rooms they cross. Being crossed by an axial line (especially with a high integration value) usually points to the visual significance of such spaces. In this regard, two features of crossing spaces by axial lines were selected as method of analysing Victorian and Prairie houses. The first feature is based on the sequence of spaces crossed by the prominent axial lines. The second approach is an analysis of the major spaces being cross without considering the sequence.

In both cases, the focus is on the highly-integrated axial lines (HIALs), which are the axial lines with the *top* integration values. Such lines may reveal the most prominent vistas in the houses. Nevertheless, it is crucial to first define the concept of "top" integration values. In many houses there is more than one axial line which has the highest integration values. In some houses, the difference between the first and second value is very small compared to the difference from the next highest value. In order to have a useful scale for identifying the HIALs, an arbitrary number of 20% was selected to represent the range of higher integration. In other words, if the integration value of an axial line falls in the highest 20% portion between the maximum and minimum integration values, that line is considered an HIAL (Table 4.3 shows an example). The only exception is when there is an all-connected line in the space for which there is no integration value (or $i = \infty$). In this case, only that line was considered an HIAL.

Table 4.3. An example for finding HIALs

Index	Integration value	Min-max range	20% top range	Is it an HIAL?
1	0.45 (min)			
2	0.80			
3	1.42			
4	**3.50 (max)**			YES
5	**2.91**	0.45 – 3.50	2.89 - 3.50	YES
6	0.45			
7	1.01			
8	0.80			
9	2.70			

Returning to the two features of axial lines, the HIALs were recorded based on the spaces they cross. For example, a line which passes the dining room and living rooms was labelled *DxL*, after the acronyms of the respective spaces. If this line also crosses the hall, it would also be a *DxHxL* line. The comparison is based on the percentage of houses in which certain HIALs exist.

The second feature is the spaces which are crossed by the HIALs. Being crossed by an axial line indicates being located on a visual axis. However, this does not reveal significant information about that space as it is not clear what part of the space is crossed. In both Victorian and Prairie houses, there is usually a distinction between the quality of activities hosted in the margins and the centre of the spaces. Arguably, most social activities are held at a certain distance from the bounding walls, while the margins are reserved for cupboards, windows, circulation, etc. Therefore, a distinction was made for classifying the part of spaces crossed by HIALs: the *side* of a room is one construction grid unit away from the surrounding walls. The size of construction unit is identified approximately by the width of stairs, which represents a minimum width for circulation. Whatever is left of the room was labelled *inside.* Figure 4.5 shows an example of these locations. This system of labelling was only applied for larger rooms (parlour, dining room, and often hall and kitchen). For smaller rooms (pantry and entry), the whole of the space was considered *inside*.

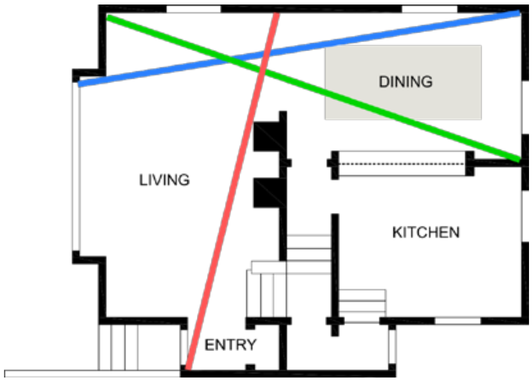


Figure 4.5. The location of the highly-integrated axial line in regard to dining room: inside (green), side (blue) and outside (red).

b) Dual axial map

The use of dual axial maps is relatively new and limited in the context of building interiors (see 3.3.2). The main focus of studies on this variant has been on the integration values of the intersections (e.g., Dawes & Ostwald, 2013b). The more integrated intersections identify points in the space with potentially high visual significance, especially in regard to surveillance. In this thesis, these intersections are called *highly integrated intersections* (HIX). The creation of dual axial maps and the calculation of the integration values of intersection were performed by DAG software (see 4.5.3) based on the imported fewest lines map from depthmapX. The identification of the highly integrated intersections (HIX) was done with the same logic as for the HIALs (i.e. 20% top range). Similar to primal axial lines, the intersections were also identified by the space in which they are located. However, the inside/side distinction is not considered for them.

4.4.10. Summary of measurements

Overall, there are nine measurement techniques in twenty-three variations considered in this thesis, which are listed in Table 4.4. Most measures are presented for both stages in the results chapters. There are different reasons for not including certain measures in one of the stages: Rings and axial intelligibility are limited only to Stage I, as their variation was too low to indicate any usefulness for further study in Stage II. The visual depth of fireplace is only used in Stage II because of the previously-mentioned fundamental difference in the fireplace of the selected Victorian houses (4.4.6). The dual axial measures are also limited to Stage II as they are not directly relevant to the investigated claims about the Victorian houses.

Table 4.4 also contains the tool used to calculate each of the measures. Most of the measures were initially calculated by depthmapX. Measures of step depths and interspatial depths were carried out in Viraph. Most of the raw results of either tools were further processed using Microsoft Excel.

There are, however, many additional space syntax measures which are not used in this thesis. The main reasons for not using them here is that most of them are not relevant to the investigation of claims about Prairie and Victorian houses. Furthermore, given the time limitation and scope of this PhD programme, it was not possible to use all – or even a majority – of space syntax techniques.

Table 4.4. The list of measures used in this thesis.

Mapping	Measures	Variant / application	Measured Claims	Stages	Tools
Convex	Intelligibility	-	Holistic space	both	depthmapX
	Integration value	Integration rankings	Inwardness	both	depthmapX
		Genotypical sequences		I	depthmapX
		Integration difference	Inwardness	both	depthmapX
	Rings	-	Ringiness	I	visual observation
Isovist / visibility graph	Angular Mean Depth	Holistic (mean)	Holistic space	both	depthmapX
		Local (rooms)	Room integration	both	depthmapX
		AMD sequences (rooms)		I	depthmapX
		Interspatial depths (between rooms)	Desirable interactions	both	Viraph
		Interspatial sequences		both	Viraph
		Visual depth of the fireplace	Central fireplace	II	depthmapX
	Connectivity/isovist area	Holistic (mean)	Holistic space	both	depthmapX
		Local (rooms)	Room integration	both	depthmapX
		Sequences (rooms)		both	depthmapX
	Step mean depth	Holistic (mean)	Holistic space	both	Viraph
		Local (rooms)	Room integration	both	Viraph
		SMD sequences (rooms)		both	Viraph
		Interspatial depth		both	Viraph
		Interspatial sequences		both	Viraph
Axial	Intelligibility		Holistic space	I	depthmapX
	Integration (primal)	highly integrated axial lines		Both	depthmapX
		crossed spaces by major lines		Both	depthmapX
	Integration (dual)	spaces hosting major intersections		II	DAG

4.5. Tools

There are three computational tools used for the raw measurements of the space syntax parameters, depthmapX (Varoudis, 2014), the standard, and Viraph and DAG, both of which were developed by the author. Apart from these, many other computational tools such as AutoCAD and Microsoft Excel are used for preparation and data analysis. In this section, the tools employed in the space syntax measurements are explained.

4.5.1. depthMap

depthMap is probably the most commonly-used software for space syntax measurements in the architectural discipline. Its first version was programmed in C++ language by UCL scholars in 2001 (Turner, 2001b) and was upgraded to the present day as depthMapX (Varoudis, 2014). For this study, the latest version (depthMapX) is used; however, the generic term depthMap is used hereafter when discussing the software.

depthMap is able to import DXF-format CAD files as a base map. It automatically generates axial and visibility grid maps after the user selects an inside point and the grid's unit size (for the visibility grid). On the other hand, the convex map is generated manually by drawing each boundary polygon and linking them together.

depthMap provides numerous measure for all three space syntax mappings. For convex and axial mapping, it offers mean depth (MD), relative asymmetry (RA and RRA), integration (i), choice, and control value, among others. For visibility graph analysis (VGA), connectivity, thorough vision, angular mean depth (AMD), visual integration (VI, only in depthMap 10 and presumably before), and some geometric properties of isovists are provided. The results are available as graphic visualisation and tabulated data. In the graphic visualisation, colours represent the range of result values. They can be seen both in the software or as an exported SVG (sizeable vector graphic) file. The actual numerical result is also accessible by hovering the mouse cursor over the selected element(s). In the case of multiple selections, the software shows the average of the selections. The table list is also available in the software and as an exported spreadsheet file (in CSV format). The mapping elements are represented by numbers, and so it is not easy to determine what space they represent. Nevertheless, the spreadsheet is helpful to perform global measurements on the results (such as intelligibility).

depthMap also has a number of shortcomings in regard to the measures described in the previous section (4.4). While it does measure visual integration (based on step mean depth, SMD) in VGA, it does not output the raw SMD values. It also does not have a direct measurement for dual axial mapping. In addition, depthMap does not present the averaged depth between two areas. To address these specific issues, two new computational tools were developed by the author and are explained in the following subsections.

4.5.2. Viraph

An important issue with depthMap is the long time – up to hours – that it takes to calculate angular measures. This issue was the initial purpose of developing Viraph (the name comes from combining "visibility" and "graph"). Viraph, developed in Java language, imports AutoCAD DXF files and similar to depthMap, and generates the visibility grid by selecting an inside point and the size of the grid. It divides the plan into convex polygons which are a number of mutually-visible grid cells (they should not be confused with the convex mapping). As a result the plan would be represented by a number of neighbouring polygons which border each other with straight edges. Basically, the shortest path between any two points on the plan will consist of lines connecting the end of these edges (unless the points are mutually visible). Therefore, to find the shortest path between two points, Viraph simply navigates different possible combinations of those connecting lines to find the shortest angular path. For shortest step path, it uses Dijkstra's algorithm (1959) for those connecting lines.

The software allows the user to decide how accurate (compared to depthMap) the results should be, which significantly affects the calculation speed. The accuracy is decreased by combining neighbouring ends of connecting lines. A 5% average decrease in accuracy (only in angular measurements) (see Appendix III) may contribute up to a 10-times increase in speed depending on the plan geometry.

Apart from the faster measurement of angular depth, Viraph offers step mean depth (SMD) of the grid points and the interspatial depths (the average step or angular depth between two areas or sets of points). Similar to depthMap, results are recordable both on screen or in a saveable spreadsheet.

Calculating the interspatial depth is made possible by drawing polygonal areas on the grid and labelling them as spaces. During the calculation of individual point-to-point depths (for measuring mean depth values), the software checks if the two points are located inside two differently labelled spaces. The software records any point-to-point depth where both points are located in different spaces and uses this depth to calculate the interspatial depth between spaces.

4.5.3. Dual Axial Grapher (DAG)

Dual Axial Grapher (DAG) is a Java application developed by the author that calculates common space syntax measures for dual axial maps. The software imports the SVG-format exported screen of depthMap's fewest-line axial maps (i.e. the generation of the axial map is done by depthMap). DAG detects the intersection of the axial lines and devises the dual axial map as proposed using Batty's (2003) methodology. In DAG, it is possible to choose whether and which line endings are included (manually, by having unique vertex visibility – as in Dawes & Ostwald 2013b) – by absolute, or relative length). However, in this research, all the endings are considered.

DAG calculates basic space syntax measures (mean depth, integration, RA, control value) using Dijkstra's algorithm for the base depth finding procedure. The results are saved in spreadsheets and in JPEG picture format where colours, sizes, and numbers indicate the measured values. More information is provided in Appendix III.

4.5.4. Examples of results

Figures 4.6 and 4.7 show examples of visualised analysis for a Victorian house (Dwelling of Moderate Cost, Plate 27) and a Prairie houses (Adams House, built in 1905). The colours on the figures vary based on the actual values (warmer and cooler colours indicate higher and lower values, respectively; the colour grey in axial map represents an unmeasurably high (∞) integration value). The convex, angular mean depth and primal axial maps are drawn by depthMapX; the step mean depth is visualised by Viraph and the dual axial map is created by DAG. The labels on the plans are acronyms for living room, kitchen, dining room, hall, entry and pantry.

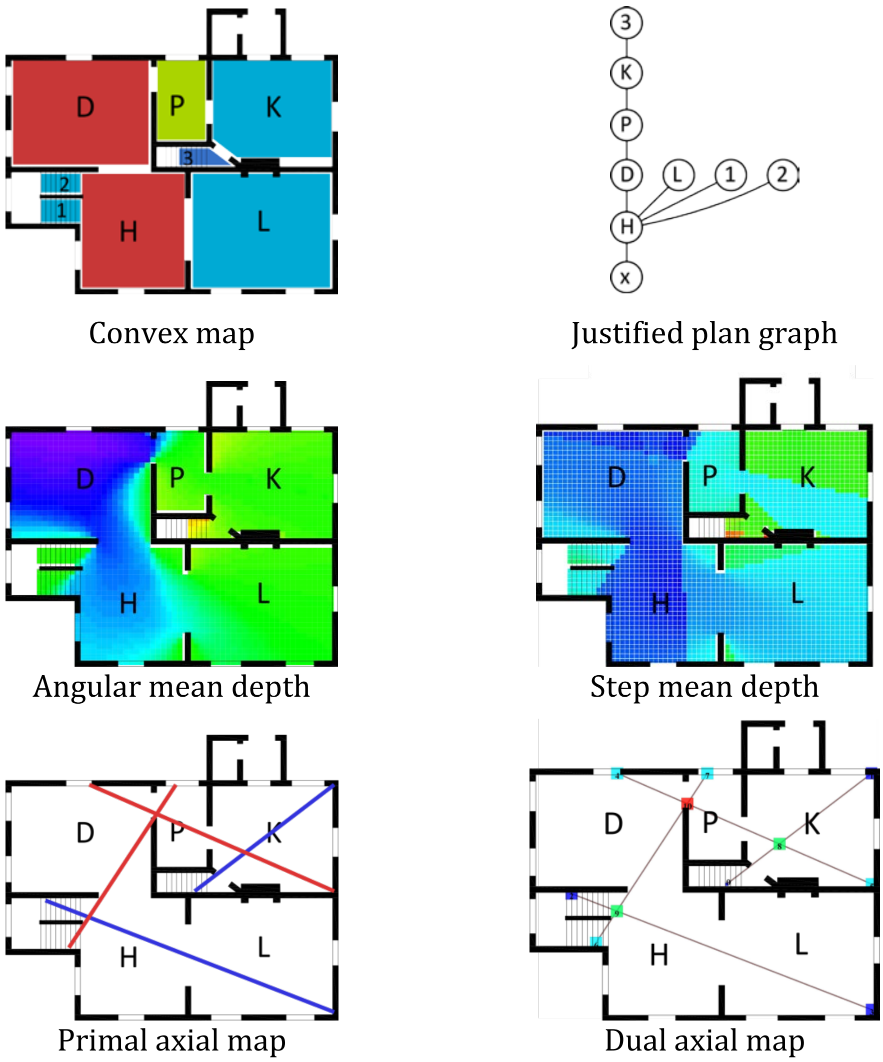


Figure 4.6. Visualised results of the measurements for Dwelling of Moderate Cost, Plate 27.

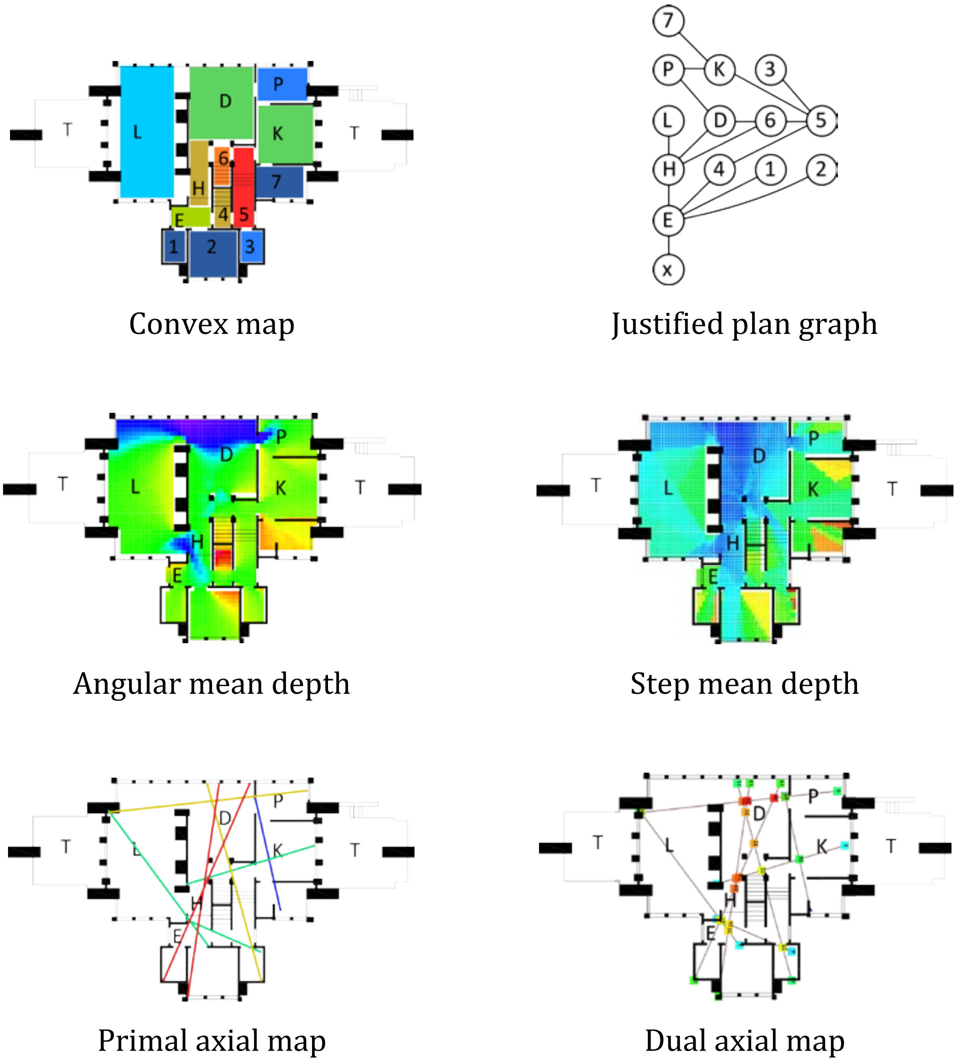


Figure 4.7. Visualised results of the measurements for Adams house.

4.6. Statistics and visualisation

In this section, the ways of visualisation and statistical analysis of the results are discussed. In general, there are four spatial parameters analysed in this thesis, including the individual houses, the layout variations (i.e. styles, subtypes, service connection types), spaces (the six major spaces, or their interspatial connection) and space syntax measures. Two methods of visualisation are provided to intelligibly display the results. In the first method, each graph contains the results for one topological measure (such as frequency of space sequences) of a particular space (such as the living room)

(Figure 4.8). In the second method, each graph contains the results for one topological measure regarding one layout variation across different spaces (Figure 4.9).

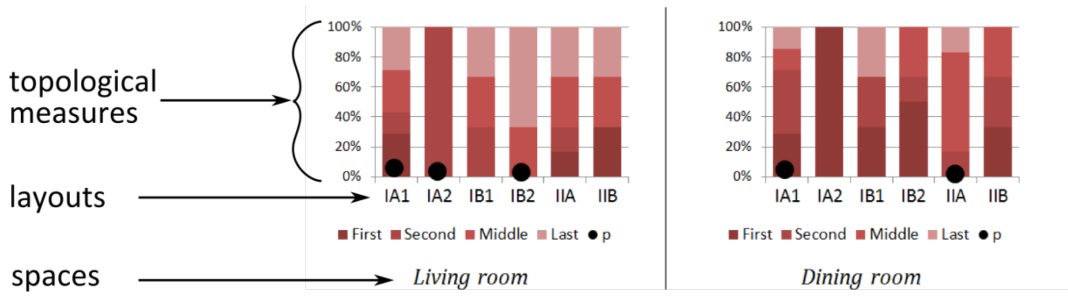


Figure 4.8. The layout-based visualisation: layouts are on the X-axis while graphs are separated based on functions.

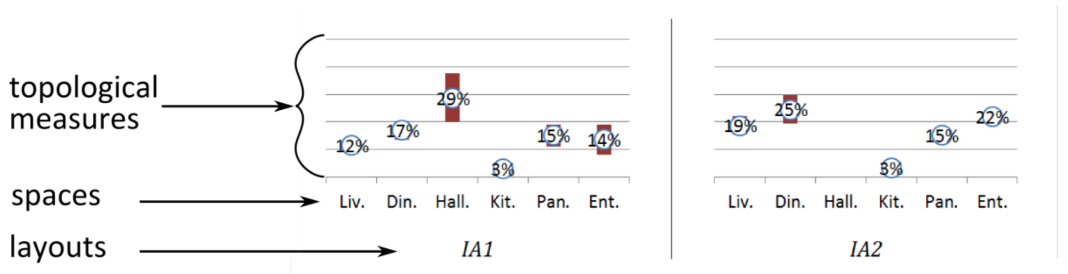


Figure 4.9. The function-based visualisation: functions or spaces are on the X-axis while graphs are separated based on layouts.

The statistical analysis depends on whether the data is qualitative or quantitative. For qualitative results (such as the existence of rings, or the position of highly integrated axial lines) the figures are shown based on the percentage of the houses which feature a respective qualitative category. Considering the discrete nature of this value type, Fisher's exact test (Mehta & Patel, 1983) was considered as suitable for investigating the significance of observable distribution patterns. Fisher's test was preferred because of the low number of samples in some of the categories.

For quantitative results (such as depth values), the average and standard deviations were used. The statistical analysis was endorsed by implementing Student's T-test (Walck, 2007). Considering the varying number of cases in each cluster, the t-test was carried out as two-tailed and unequal variance, using Microsoft Excel's T.TEST function.

As mentioned in different subsections of 4.4 the thesis also includes the comparison between the ranking of values. While the basis of the ranking values is quantitative, the rankings are themselves qualitative and are treated as the qualitative results above. The ranking system is only applied to spaces or interspatial categories. An issue is found when the spaces (pantry, entry or hall) are absent in some the houses and so are not considered in the ranking system. This issue makes one side of the ranking unstable (while there are always ranks 1 to 4, ranks 5 to 6 could be absent). To resolve this issue, ranks are simplified by combining the unstable end of the ranking scale in the following manner: ranks 3 and 4 are considered "middle" and ranks 5 and 6 are considered "last".

The ranking system is also shown in the form of genotypical inequality which we call a "Sequence" in this thesis. This form is used for capturing the most common genotypical tendencies. This inequality has four components including:

- The names of spaces or a spatial group.
- The symbol "<" or ">" which indicates the comparative relationship between the measures of the spaces on the either sides of the symbols. Another symbol "~" which indicates indifference to the amount of the measures.
- Brackets ( ) indicate that the contained space may not be present in all houses.

An example is shown below (Sequence 4.10):

(4.10)

Dining room < (Hall) ~ Living room < Kitchen

Regardless of the results type, the statistical significance was considered when the output p-value of the statistical tests (Fisher's or t-test) was smaller than 0.05 (notion taken from Salkind, 2006, p. 890). In this case, the category with $p<0.05$ had a data distribution significantly different from the rest of categories in a graph, collectively. This significance is usually shown as a black circle on the X-axis of the category throughout the thesis (Figure 4.10).

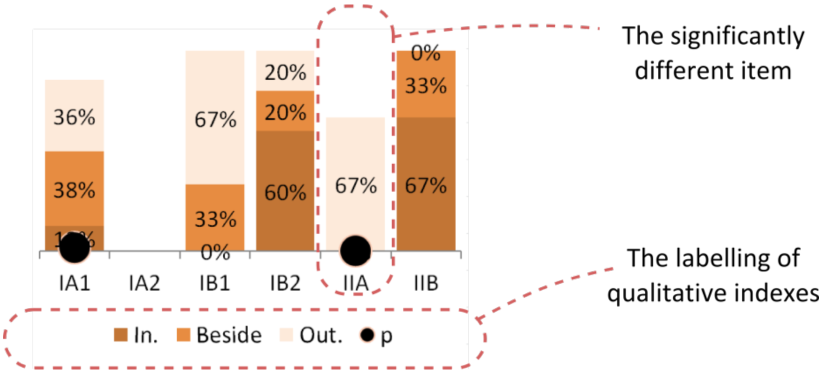


Figure 4.10. A sample of visualising qualitative indexes

4.7. Limitations

The focus and scope of this research have led to a number of practical limitations. In summary, the limitations are in three areas: the usefulness of the selected space syntax techniques and tools, the inclusiveness of the selected cases, and the preparation of cases. In this section, these limitations are addressed.

The first of the limitations is the well-established focus of the space syntax theory. As mentioned in Chapter 3, space syntax reduces the architectural features of space to gross geometry of permanent boundaries. Therefore, both the analysis and results of this research are refined only for this aspect of design. In this case, the analysis of the claims found in the literature and the interpretation of the respective results are only applicable to the context of space syntax, and particularly to the techniques used in this thesis.

This focus has two facets. Firstly, many of the claims—and further analysed spatial properties—have multiple dimensions in addition to the measured topology. Secondly, as the history of space syntax research has shown, it is always possible that a commonly-used technique may be rendered unsuitable while a less-focused technique may become relevant to a spatial property. Within the timeframe allowed for the present research, this study has tried to use a comprehensive set of relevant techniques to balance the possible limitations. Furthermore, the two tools developed by the author for visibility graph analysis are not yet published or formally peer-reviewed, although their results match those of depthMap (see Appendix III).

The second aspect of the limitations relates to the process of the selection of the cases for both styles. The selected cases are not necessarily representative of the whole of Victorian or Prairie style houses. Regarding Victorian houses, the supposedly more Prairie-like houses (e.g., by Richardson & Price, see 2.2.2) were not among the selected cases. Although there was no deliberation in this choice (as houses were selected from a "random" Victorian houses catalogue), the exclusion of these cases may emphasise the differences between the styles. As mentioned in 4.3.1, Victorian houses are selected from Cirker's (1996) collection, which itself was a selection of houses published in *Scientific American: Architects and Builders Edition,* between 1885 and 1894. However, it is unclear whether Cirker's 1996 selections, include all of the original cases in *Scientific American* or just a subset.

Regarding the Prairie houses, the restriction of selected houses to those with simple-plans, without extended spaces, may raise the issue of the representativeness of these cases, which affects the efficiency of this study to address claims about the Prairie style as a singular concept. The same limitation is true of the representativeness of the selected Victorian houses in regard to their spatial programme. Nevertheless, the current case selection is a balanced effort given the scope of the PhD. This selection facilitates the comparison between the cases, which is one of the main objectives of this research. A more comprehensive set of cases for either style would not have been able to fit in this allowed timeframe; further, it may have also required a more complex methodology, with potentially new issues and complications.

The small number (27) of the selected Prairie style houses also limits the statistical analysis of the results in Stage II, especially for the smaller sample size of the subtypes IA2, IB1, and IIB. However, this issue originated from the limitation in the selection criteria. If the selection criteria were broader, then the comparability of results would have been problematic regarding the functional differences in the results. Similarly, if there were some alternative selection criteria, they would not have fitted into the existing layout categories.

The third aspect of limitations involves the preparation of the cases for analysis. One dimension of this limitation is the focus of the research on social boundaries instead of precise convex boundaries as indicators of the spaces. This focus is widely used by space syntax researchers (Peponis & Wineman, 2005) and in the case of this thesis reduces the difficulty of the comparability of the functions in cases where two or more convex spaces are related to functions.

A further issue in the preparation of the cases is the identification of the major spaces. As mentioned in 4.3.2, there is a problem in the distinction between hall and entry in some Prairie houses, when only one of them exists. While the author has tried to provide a method for objectively defining either of two, the selection of this method is itself subjective. Nevertheless, this limitation could have also been said about any other ways to select such a method. Another minor problem is related to the possibly unidentified space under staircases, particularly in Victorian houses.

In general, because of the focus of the research, a number of otherwise relevant aspects of the topic are excluded. While these exclusions pose some limitations for a comprehensive achievement of the research's objective, they are necessary to balance the scope and timeframe of the research.

5. Comparing Prairie and Victorian houses

5.1. Introduction

In Chapter 2 a number of spatial properties were listed for the Prairie house. Those spatial properties are, in their description, relative to the Victorian houses. Most of these spatial claims were initially introduced by Wright himself and have been reiterated by later scholars (Giedion, 1962; Benevolo, 1971; Twombly, 1979; Curtis, 1996; Maddex, 2000, 2002). The defined spatial properties are usually derived from a visual analysis of the plans or forms, or cite the experience of the users. However, there has been no formal comparison between the two styles (Prairie and Victorian) to verify these claims. This chapter attempts to examine the claimed spatial innovations by comparing the Victorian and Prairie styles using techniques of space syntax theory (as introduced in Chapter 3). Below is a summary of the claims:

1. Prairie style houses are more holistic and integrated compared with their Victorian predecessors.
2. Prairie (main) rooms are less isolated and more integrated into the whole of the building.
3. Prairie spaces are friendlier and more intimate to intra-family social life.
4. There is more circularity inside a typical Prairie house.
5. There is more comparative desirability of connections between spaces in a typical Prairie house.

6. The fireplace has a focal position in a Prairie house. As mentioned in 4.4.6, the comparison between the fireplaces in the two styles will be problematic. Therefore, this claim is separately measured in Chapter 7.

In this regard the chapter pursues two goals. The first goal is to understand whether (and to what extent) the claimed spatial innovations for Prairie houses are also supported by space syntax methods. The second goal of this chapter is to identify further differences or similarities between the spatial configurations of the two styles by applying various techniques of space syntax.

For these purposes, a case study was conducted involving 27 Prairie and 15 Victorian houses with “simple” plan layout (see 4.3.1). Considering the importance of the area of spaces in the measures (as explained in 4.3.3), the next section of this chapter provides the analysis of the area of the major spaces in the two styles. This section is followed by five sections which discuss five of the six claims in the literature (wholeness, integration of spaces, inwardness, circularity, and interspatial depths). While the focus of each section is mainly on examining the claims, they also attempt to discover any similarities and differences found in the measures. Finally, section 5.8 compares the axial mapping of the Victorian and Prairie houses.

5.2. Size of spaces

As mentioned in section 4.4.2, the size of spaces may affect some of the topological visual measures, especially in the visibility graph analysis. Figure 5.1 shows the relative size (in percentage of total area of the house) of the six major spaces in Victorian and Prairie style houses. In this figure, the red-hued diamond markers indicate the standard deviations while the black circles on the X-axis indicate the statistical validity ($p < 0.05$) of the observable differences in the respective space. The bar chart shows the relative area of the spaces.

As can be seen, there are three major differences between the styles, in the parlour/living room, kitchen, and entry. The Prairie living room is on average 33% larger than the Victorian parlour (32% of the house versus 24%). On the other hand, the Prairie kitchen covers 6% less area of the house than the Victorian kitchen (13% versus 19%). The Prairie entry (5%) also covers more area than the Victorian entry (3%). The sum of the area of the six major spaces is slightly larger in the Prairie houses (83% compared to 80%), pointing to a reduction of non-major spaces (mostly circulation) in the Prairie houses. Nevertheless, the occupied area of the other three major spaces (dining room, hall, and pantry) are similar between the two styles; it seems the architecture has cut space from the kitchen and added it to the living room and entry in the Prairie houses. This can be seen as evidence of the focus of Prairie houses on the social activities of the house.

The differences in size can affect the measurement in the following sections in several ways. Firstly, a larger living room means that the neighbouring spaces (e.g., dining room and hall) may probably have a higher area of the living room visible to them, and so this affects the visibility measures.

Secondly, the allocation of more area to the social spaces may be a reflection of their higher organisational role. As for the entry, a reason for having a higher area is that the Prairie entry may constitute a separate “square”, while in Victorian houses it is usually a part of or an addition to the hall “square”. The reduction of kitchen space may also reflect advancements in the production of smaller appliances as well as invention of early electric heating, ventilation and air conditioning systems which were not available in the Victorian era.

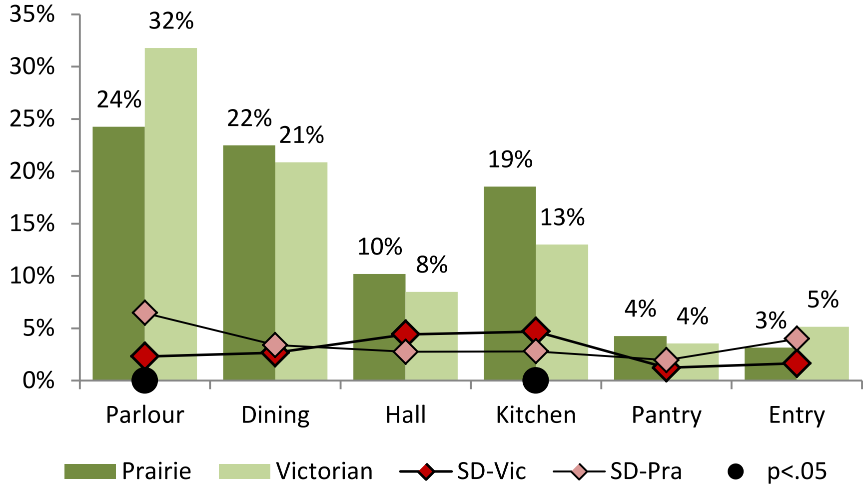


Figure 5.1. The average relative size of the six major spaces in Victorian and Prairie spaces.

In this context, if the large living room and smaller kitchen are considered as features of the Prairie style, it is possible to find which Prairie houses are more "Prairie-like" by comparing the relative size of their living room and kitchen with each other and their respective average values (that is, if their living room is larger than average and their kitchen smaller than average). In this case, the houses for Baker, Adams (scheme #1) and Millard are the most Prairie-like houses (with respective sizes of living room at 39.8%, 35.5% and 33.5%, and kitchen at 11.7%, 10.7% and 10.3%; see Table II.13 in Appendix II). On the other hand, Houses for Kellogg, Roberts and Fuller are the least Prairie (respective sizes of living rooms at 24.8%, 31.7% and 29.4%, and kitchens at 14.4%, 18.7% and 16.0%).

5.3. Holistic space

Wright's concept of "wholeness" is derived from the capacity to understand or communicate the properties of a larger space from a single experience of it. As explained in Section 4.4.1, one aspect of this interpretation of Wrights' wholeness is similar to the space syntax concept of intelligibility – the degree of correlation between local and global measures of connection. In this regard, two variants of intelligibility – convex and primal axial – were used for the measurement. The former reveals a house's organisational clarity, while the latter indicates the clarity of movement. Regarding the claimed spatial innovations (5.1), the first hypothesis in this section is:

a. Prairie houses have higher convex and primal axial intelligibility than Victorian houses.

While intelligibility is a combinatory measure of both local and global data, it is also possible to interpret the wholeness of a plan using individual global and local measures. These measures, as explained in 4.4.1, are the global measure of mean depth (both angular and step) in isovist maps (or visibility graphs) which reveals the degree of integration of the space, and the local measure of connectivity (C) – or isovist area (IA) – in visibility graphs which indicates the area of the whole space visible from an average point within it. These values may reveal alternative facets of the concept of "wholeness". In this regard, it is expected that:

b. Prairie houses have lower SMD and AMD values than Victorian houses.

Figure 5.2 shows the average results of these five values for both styles. In this figure, the average values are displayed by bar graphs and the standard deviations are represented by diamond markers. The black circles on the X-axis indicate the *p*-value (significance) is under 0.05. Table 5.1 shows the results, their standard deviation, and *p*-value significance of the two-tailed t-test.

The results show that there is no significant difference between the two styles in any of the holistic measures used for analysing different aspects of wholeness. Therefore, the spatial claim of wholeness in favour of Prairie houses is not supported by these space syntax measures. The results show that the average Victorian and Prairie houses (to the extent of the selected cases) do not differ in regard to the selected holistic measures.

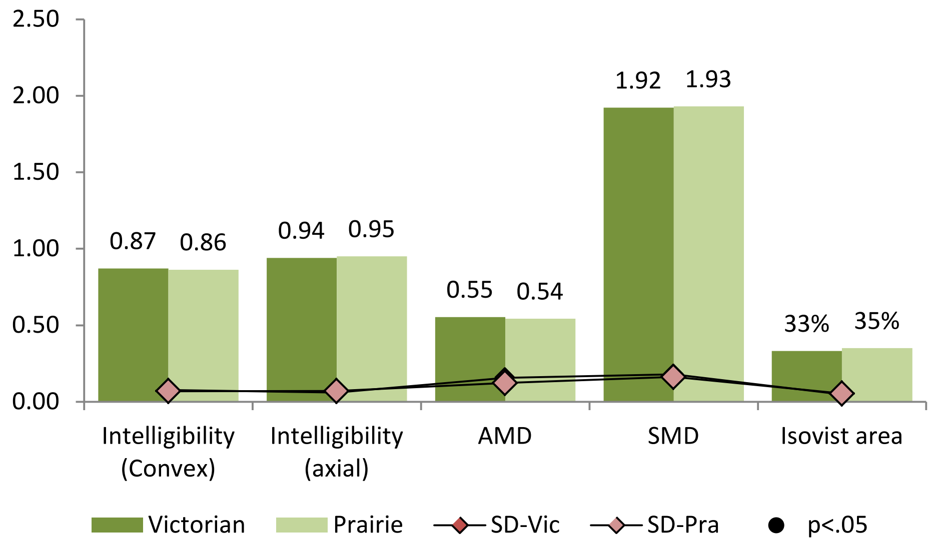


Figure 5.2. Holistic measures for different facets of Wright's definition of "wholeness" in interior spaces, charted for Victorian and Prairie houses.

Table 5.1. Holistic measures for different facets of Wright's definition of "wholeness" in interior spaces

		Intelligibility (Convex)	**Intelligibility (axial)**	**AMD**	**SMD**	**Isovist area**
Victorian	mean	0.87	0.94	0.55	1.92	0.33
	SD	*0.08*	*0.06*	*0.16*	*0.18*	*0.05*
Prairie	mean	0.86	0.95	0.54	1.93	0.35
	SD	*0.09*	*0.05*	*0.12*	*0.16*	*0.05*
p-value		0.74	0.65	0.81	0.89	0.19

Considering the individual houses, we would expect that some would be closer to the expectations for a Prairie house. The expectation would be a lower AMD or SMD, and also lower IA. This combination implies higher indirect visual connections (AMD and SMD) and lower direct connection (IA) in order to serve the purpose of "mystery" as noted by Brooks (1979). In this regard, houses for Larwill, Fuller, Roberts and Martin are the most Prairie-like (see the last columns in Tables II.16, II.18 and II.20 in Appendix II for the numerical results of respective holistic IA, SMD and AMD values). Interestingly, two of these houses (Fuller and Roberts) have been deemed as the least Prairie, in terms of room sizes in the previous section. On the other hand, considering the average values as representative markers, houses for Nicholas and Gale are the most representative of the Prairie houses.

Nevertheless, contrasting our interpretation of Brooks' notion of "mystery", the higher holistic IA is evidently exclusive to Prairie houses as there are 26% of the houses (seven out of twenty-seven) with $IA_{HOLISTIC} > 40\%$ comparing to only one Victorian house (6%) with such a figure (see Table II.4).

5.4. Spatial isolation

Wright and later scholars claimed that the Prairie spaces were more integrated and less isolated in the house (see 2.5.2). In other words, the spaces were visually more connected to each other. As the definition of isolation is shaped by visual factors and room area, isovist graphs are the most useful method for assessing this property among the space syntax measures (Turner & Penn, 1999). Due to the focus of the analysis on the connection between spaces, the effect of their own area was removed from the calculations (see 4.4.2).

The first subsection examines the claims in the literature. It is followed by a discussion of other implications observed in the results.

5.4.1. Examining the claims

In this subsection, the results for angular and step mean depths and relative isovist area are presented for the six major spaces including the parlour (or living room in Prairie houses), dining room, hall, kitchen, pantry and entry.

Hypothesis

Regarding the spatial claims (5.1) three hypotheses are considered:

a. Prairie spaces have a higher relative isovist area than Victorian spaces. Therefore they are directly connected to a larger portion of the house.
b. (Some) Prairie spaces have a lower depth (AMD and SMD) to the rest of the house.

Results

Figure 5.3 shows the results for the relative isovist areas of the six major spaces in Victorian and Prairie houses. In this figure, the red-hued diamond markers indicate the standard deviations and the black circles on the X-axis indicate the statistical validity ($p < 0.05$) of the observable differences in the respective space. The bar chart shows the portion of the house averagely visible from a space.

The results generally do not support hypothesis (a). There is no significant difference in relative isovist area for four of the six spaces (parlour/living room, dining room, pantry and entry). The Prairie hall is the only space supporting the hypothesis of being more connected to the rest of the house (37% versus 28%). The Prairie kitchen contradicts the hypothesis, with only 4% relative isovist area compared with the Victorian kitchen's 8%. Nevertheless, considering the undesirability of kitchen's visual connection to the rest of the house, the kitchen might not have been included in that claim.

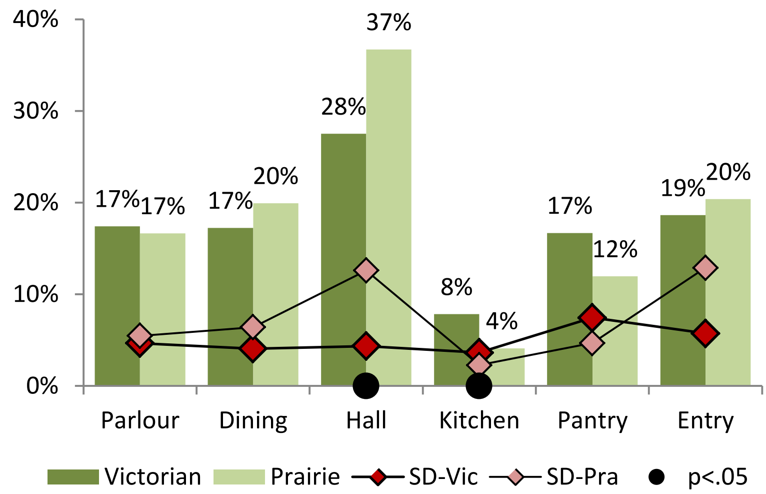


Figure 5.3. The relative isovist area of the six major spaces in Prairie and Victorian houses.

Figures 5.4 and 5.5 show the respective step (SMD) and angular (AMD) mean depths of the six major spaces in Victorian and Prairie houses. Similar to the previous graph, the black circles on X-axis indicate the statistical validity ($p < 0.05$).

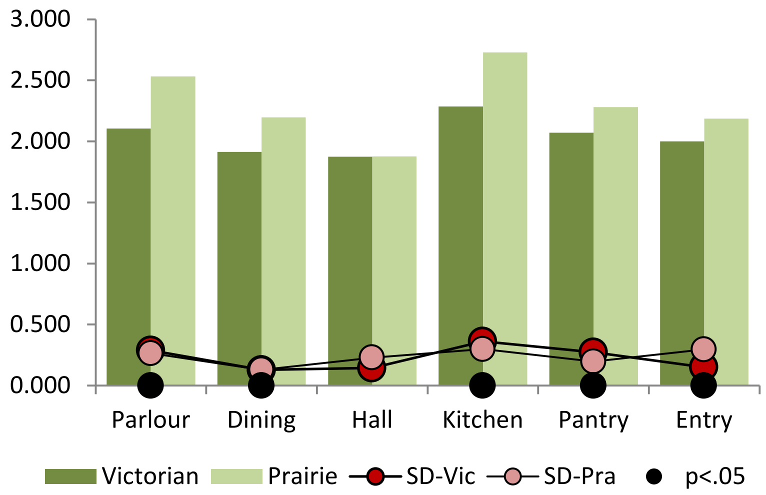


Figure 5.4. The average step mean depth of the six major spaces in the Victorian and Prairie houses.

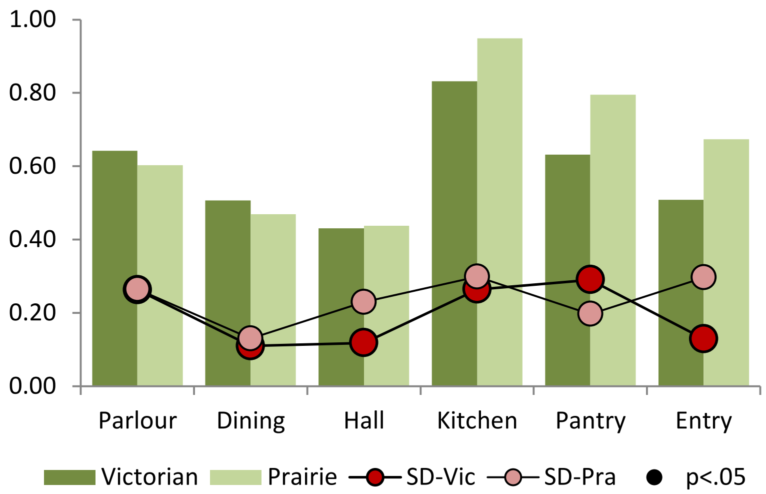


Figure 5.5. The average angular mean depth of the six major spaces in the Victorian and Prairie houses.

The AMD results demonstrate that the Prairie living and dining rooms are slightly (+ 0.04 turn) more visually integrated in the house plan than the Victorian parlour and dining room. Apart from this, the kitchen, pantry, and entry spaces are more visually integrated into Prairie houses. Nevertheless, due to the high standard deviation, these differences are not significant ($p > 0.05$). As for SMD, the results show that all spaces except the hall are significantly more visually integrated in Victorian houses ($p < 0.05$). The SMD for the hall is similar in both houses (1.88 and 1.87). In general, the results contradict hypothesis (b), as the Victorian spaces have significantly lower step depth to the rest of the house than the Prairie spaces do.

Overall, the results show that the Prairie spaces are not more integrated or connected within the house, except for the hall. Prairie halls are around 25% more visually connected to the rest of the houses (i.e. covering 9% more of the total space). If the higher isovist area of the hall is considered as a Prairie feature, then houses for Adams (scheme #2, 58.4%), Walser (55.6%) and Barnes (53.4%) feature the most Prairie-ness. Nevertheless, this consideration may undermine the implication that Prairie houses are more "mysterious" as their organisationally central space (hall) is far more directly connected to the rest of the house. However, in fact, such a high connectivity is seemingly an exclusive Prairie feature as the highest IA value for halls in the Victorian houses is 35.6%.

The Brown house is the most representative of the Prairie houses with only an average 1.4% difference from the mean IA values of the six major spaces. If we consider only the larger spaces (living and dining rooms, hall and kitchen), houses for Waller, Martin and Little are also close to the average Prairie house. Regarding the AMD values for the six major spaces, houses for Adams (scheme #1), Brown and Roberts are closest to Prairie average. However, if only the larger spaces are considered then houses for Martin, Larwill and Roberts are the most representative. The Roberts house and houses for $5000 feature closer AMD values (both for all spaces and the larger ones).

5.4.2. Further implications of visual integration measures

While the above results did not support the spatial claims, they showed several similarities between the Prairie and Victorian houses. The main similarity between the two styles is the order of the spaces in regard to the value of the measures. For the measure of isovist areas, the hall has the highest value, followed by the entry, dining and living rooms, although the difference between the latter spaces is very small. The lowest values of isovist area belong to the pantry and kitchen respectively. Therefore, the results for both styles implied the following Sequence 5.1 (the space in bracket shows it does not exist in all houses, the symbol ~ indicates indifference to order):

(5.1)

(hall) > (entry) ~ living room ~ dining room > (pantry) > kitchen

The above sequence occurs in 40% of Victorian houses and 62% of Prairie houses. Considering the length of this sequence, these figures are significant. Nevertheless, a shorter but more detailed version of this sequence shows even more prevalence. The following sequence occurs in 87% of Victorian houses and 85% of Prairie houses.

(5.2)

(hall) > dining room > living room > kitchen

These results indicate there was a recurring genotypical pattern of visual connectivity (isovist area) in both Prairie and Victorian houses, although caution must be observed as the selected cases might not be the best representatives of the styles. In any case, a reason for this order might be the size of spaces. The hall, entry, and dining room have a higher connection to the large living room or parlour, while kitchen is at best connected to small spaces like pantry.

Considering the step depth values (Figure 5.4 above), a Sequence (5.3) of SMD orders is imaginable as follows:

(5.3)

(hall) ~ dining room < living room ~ (entry) < (pantry) < (kitchen)

However, the occurrence of this sequence is low in both styles (26% for the Victorian houses and 18% for the Prairie houses) This is explainable by the small difference between the SMD values compared to the standard deviation. On the other hand, the prevalence of shorter sequences is significant. Sequence 5.4 occurs in 53% and 59% in Victorian and Prairie houses respectively, while Sequence 5.5. is present in 73% of Victorian and in 63% of the houses of the Prairie style.

Regarding the measure of angular mean depth, the order of spaces appears to be different for the styles on the graph (Figure 5.5, above). In Victorian houses, the order is sequenced as below (5.4). However, this sequence is only found in 13% of the houses.

(5.4)

(hall) < dining room < living room < kitchen

The sequence for the Prairie houses is different mainly in the position of the living room. It appears that the living room is more angularly integrated in the house, relative to other spaces. Therefore, the order of AMD values would resemble Sequence 5.5. However, similar to the Victorian houses, there are only a few houses (11%) featuring this sequence wholly:

(5.5)

(hall) < dining room < living room ~ (entry) < (pantry) < kitchen

Similar to previous measures, a shorter sequence occurs in more houses. Sequence 5.6 appears to be a common sequence featuring more than three spaces in both Victorian and Prairie houses (33% and 44% respectively). However, a longer sequence (5.7) also occurs in 46% of Victorian houses while it is not as significant in Prairie houses (22%).

(5.6)

(hall) < dining room < living room < kitchen

(5.7)

(hall) ~ dining room < living room < (entry) < kitchen

Overall, the hall generally features in the visual integration in the houses followed by the dining room in both styles. On the other hand, the kitchen is the least visually integrated. The entry and pantry usually are positioned somewhere between the dining room and kitchen in this order. The two styles also resemble each other regarding their genotypical tendencies. However, the prevalence of the genotype fades for less direct measures (isovist area > SMD > AMD).

5.5. Inwardness

It is claimed that Prairie houses are more focused on socialisation between family members than on interfamily relationships (see 2.3.5). In other words, architecturally, the Prairie house supposedly looks more inwardly than outwardly. The first subsection examines this proposition while the second subsection provides a more in-depth analysis of the measures used for inwardness.

5.5.1. Examining inwardness of Prairie houses

As explained in Section 4.4.3, the concept of inwardness can be measured in two ways: as an indicator of the contrast between a space's relationship with other indoor and outdoor spaces, and as an indicator of the integration of spaces within the interior. These two ways were the basis for forming the hypothesis.

Hypothesis

Regarding the first measurement approach, it is possible to draw a hypothesis regarding the claim of "inwardness":

a. Prairie spaces are more inward than the Victorian houses. This will particularly be visible for the parlour/living room that is considered the symbol of Victorian interfamily relationships.

The other way to approach the concept of inwardness is the integration of the more social rooms (parlour, hall, and entry) into the house. This measure of integration of course comes from the convex map, not from visibility graphs (as in 5.4). In order to have a better understanding of the role of these spaces regarding their integration values, the values are converted to ordinal ranks (see 4.6.2). In this regard, we expect that:

b. Prairie living rooms, halls, and entries have higher integration ranks than their Victorian counterparts.

Results

Figure 5.6 shows the inwardness of the six major spaces in Victorian and Prairie houses. The bar graph shows the three inwardness qualities of “inward” (green), “neutral” (grey) and “outward” (red) (see 4.4.3). The values indicate the percentage of houses in which the major spaces have the respective inwardness quality. In this figure, the black dots on X-axis represent the statistical significance of the observable differences ($p < 0.05$).

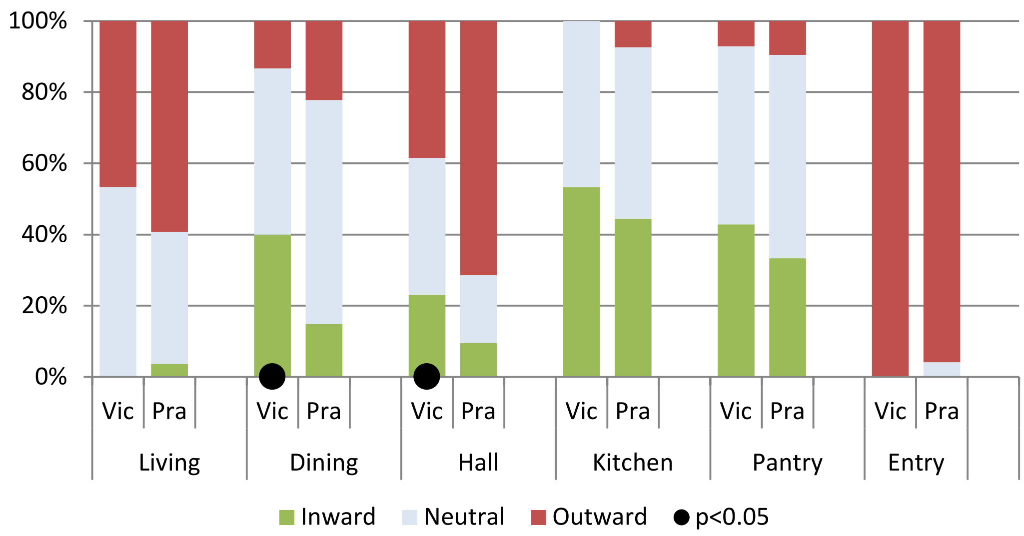


Figure 5.6. The inwardness of the six major spaces in Victorian and Prairie houses.

Contrary to the hypothesis (a), there are significantly more Prairie houses with outward spaces (except the entry) compared with Victorian houses, especially including the more outward hall (71% versus 38, and less inward dining room (15% versus 40%). If outwardness is interpreted as increased engagement with a visitor, then there is more support for the focal status of the hall.

In examining the second hypothesis (b), Figure 5.7 shows the average ordinal ranking of the integration values of the six major spaces in Prairie and Victorian houses. As can be seen there are significant differences (shown by black circles on X-Axis) in all spaces except the hall.

Regarding the hypothesis (b), the Prairie living room (30% first and second ranks) and entry (34% first and second ranks) are in fact more likely to have higher integration values in the house than the Victorian parlour and entry (no first and second ranks). This suggests that the outward social function of these two spaces is reduced in the Prairie houses. Similarly, the Prairie dining room is also more integrated in the house than the Victorian dining room.

In contrast, the kitchen has a substantially lower organisation role in the Prairie house (18% first and second ranks) than in the Victorian house (60% first and second ranks). Combining this and the results for living and dining rooms, the Prairie style appears to have shifted the organisational centre of the house more towards the social zone that parallels the change in the size of these spaces as discussed in Section 5.2.

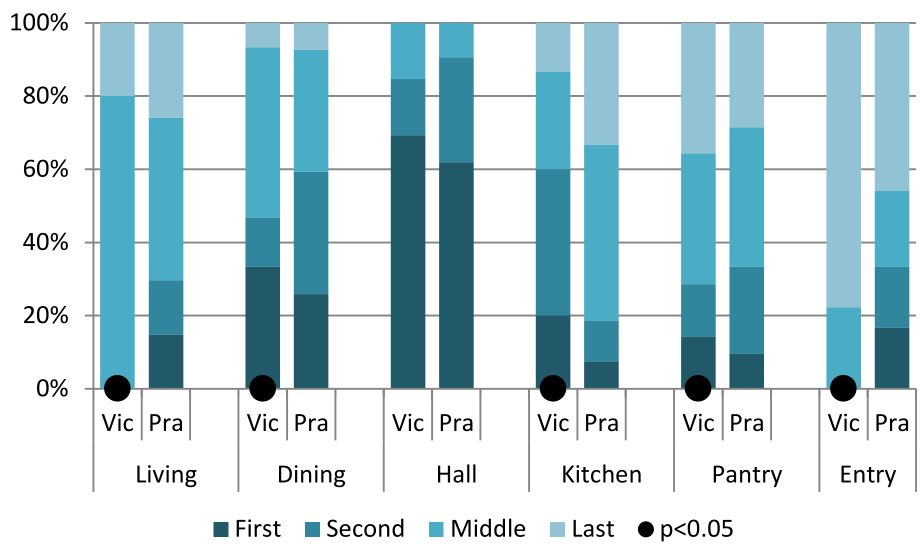


Figure 5.7. The ordinal scale for integration values of major spaces in Victorian and Prairie houses.

It seems that more prominent living rooms and entries and less significant kitchens are innovations of the Prairie style. In this regard, houses for Baker and Fuller (both with first or second ranking living room and entry, and middle or last ranking kitchen) show more Prairie features. However, considering that most Prairie houses do not differ from themselves and the Victorian houses in terms of the ranking of integration values, no certain representative or least Prairie houses is identified.

In general, the results demonstrate that Prairie houses are significantly different in their spatial organisation. The Prairie living room and entry is given a significantly greater organisational role in the house while the kitchen is less prominent. This suggests that the organisational centre of the house has shifted from the service zone in Victorian houses towards the social zone in the Prairie houses. This may also explain why the Prairie spaces were more outward in the first analysis (Figure 5.6). In this instance, the results support the hypothesis and claims in the literature about the inwardness of the social spaces in Prairie houses.

5.5.2. Comparing integration values in the two styles

The previous subsection identified an important difference between the integration order of the living room in the Victorian and Prairie houses. However, those results only provided a general picture of the order of the integration values based on single spaces. This subsection attempts to identify the prevalence of orders.

Based on Figure 5.7, the hall and dining room respectively appear to be the most integrated spaces in both styles. However, the styles differ in the next two most integrated spaces. Victorian houses appear to have more integrated kitchens and pantries, while in Prairie houses, the living room seems to be more integrated. In this regard, Sequences 5.8 and 5.9 are imaginable for the two styles respectively:

(5.8)

(hall) > dining room > kitchen > (pantry) > living room ~ (entry)

(5.9)

(hall) > dining room > living room > kitchen ~ (pantry) ~ (entry)

However, both above sequences are rare in the actual houses (6% and 7% for the respective styles). Therefore, it is necessary to simplify the sequences. For example, Sequence 5.10 is probably the longest, featuring in a significant number of Victorian houses (53%). However, it is more difficult to find such a sequence for Prairie houses. The longest sequence with a relatively common occurrence (41%) is only made of three spaces (Sequence 5.11). A reverse version of this sequence (with *kitchen > living room* instead) occurs in 29% of houses. This indicates the possibility that the Prairie houses do not have the similar degree of uniformity in the programmatic organisation of the space.

(5.10)

(hall) > dining room ~ kitchen > living room > (entry)

(5.11)

dining room > living room > kitchen

5.6. Circularity

One of the claims in the literature is that Prairie houses provide more circular access to the spaces, especially in the "living areas" (which is interpreted as the social zone of the house). The analysis of this claim is based on the visual observation of the convex map graphs of the houses and a recording of the number and quality of the rings. As explained in 4.4.4, four aspects of circulation in the houses were considered including rings, subrings, universal rings, and universal paths. In this section the houses of the two styles are compared with each other based on the presence of these four aspects.

Hypothesis

The circularity hypothesis is based on the claim of more circular access and inter-connection of the Prairie house:

a. Prairie houses have more rings (including both sub-rings and universal rings).

Furthermore, it is also claimed that such a circulation is more focused on the living areas of the Prairie houses. One interpretation of this claim can be that the living areas (living and dining rooms and hall) are more included in rings:

b. More Prairie houses will have living areas included in rings than Victorian houses.

Results

In the first instance (hypothesis a), the results (Figure 5.8) confirm the expectation that there are more Prairie houses with rings (+14%). Furthermore, there are also slightly more Prairie houses with complex rings (that is, with sub-rings). However, there are more universal rings and paths in Victorian houses. This suggests the possibility that the rings of the Prairie houses may be confined to certain spaces.

Further, the results are mixed in support of the second hypothesis (b) that the living areas are more included in this ringed circulation. While there are more Prairie houses with dining rooms and halls included in the rings, there are slightly fewer living rooms included in rings (Figure 5.9). Accordingly, the role of living areas in rings is more prominent in Victorian houses as, for example, the living room prevails in 91% of rings (compared to 71% in Prairie houses). In contrast, there are significantly more pantries and entries included in the rings in Prairie houses (Figure 5.10). The pantry is one of the most inwardly-focussed spaces, while the entry is the most outward space. The increased likeliness of both spaces (pantries and entries) occurring in a ring in Prairie houses suggests a new dimension to the inwardness claim in the previous subsection. It is possible that the reason for more outward Prairie spaces (in the first inwardness measure) would be the lower segregation of outside and inside.

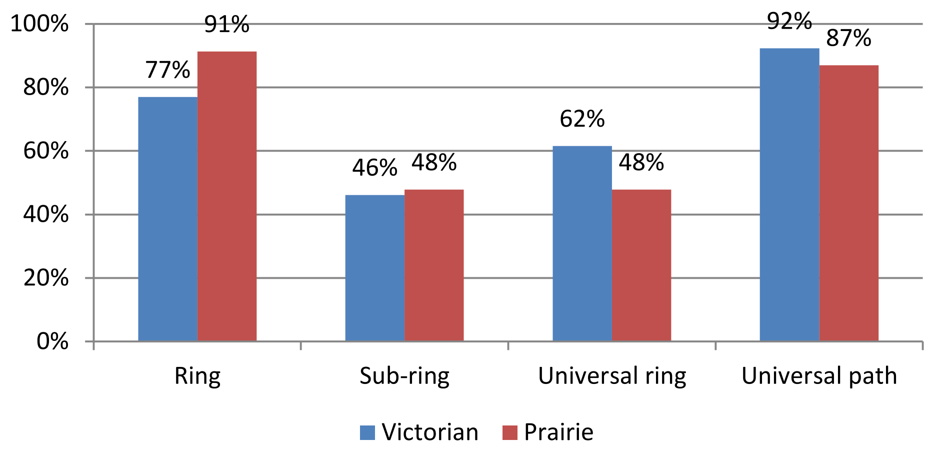


Figure 5.8. The percentage of houses with rings and paths in the Victorian and Prairie styles.

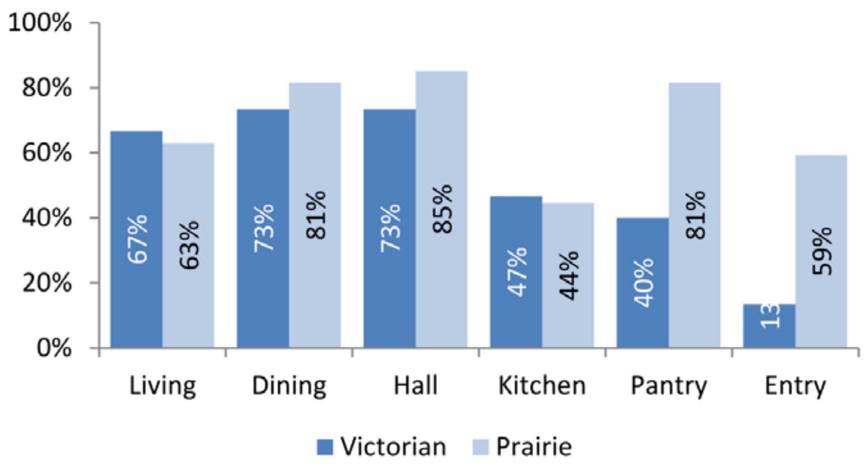


Figure 5.9. The percentage of houses with major spaces included in rings in Prairie and Victorian styles.

This set of results generally supports the view presented in the literature that it is more likely for the Prairie houses to have a ring connecting interior spaces. However, considering that 77% of the Victorian houses also have such a ring, it could hardly be considered a unique feature of the Prairie houses, and it is not a sign of a substantial innovation, particularly considering the rings in the Victorian houses are syntactically larger (covering more spaces). Overall, while the argument that Prairie houses feature a higher degree of circularity is supported by the study, the results do not, in themselves, support the argument that it is an innovation or a major departure from the pattern in the Victorian houses.

5.7. Interspatial depth

An important feature of Victorian houses was the visual separation of social and service spaces. This feature evidently continued on to later in the Prairie era. In this section, this feature is examined by interspatial step and angular depths as explained in Section 4.4.5. This includes a comparison of both the value and order of the interspatial depth.

The interspatial depths were measured between entry, parlour/living room, dining room, and kitchen. The depths between entry and the other three spaces indicate how they are perceived from the viewpoint of a visitor. The depths between the other three spaces reveal the visual interactions between three main functional spaces of the house.

Figures 5.10 and 5.11 show the respective step and angular interspatial depth between the four spaces. The labels on the X-axis represent the acronym for the connected spaces (L-D for living and dining rooms, L-K for living room and kitchen, D-K for dining room and kitchen, E-L, E-D and E-K for the depths from entry to the living room, dining room and kitchen, respectively). In these figures, bar graphs stand for the average values and the red-hued diamond markers indicate the standard deviations.

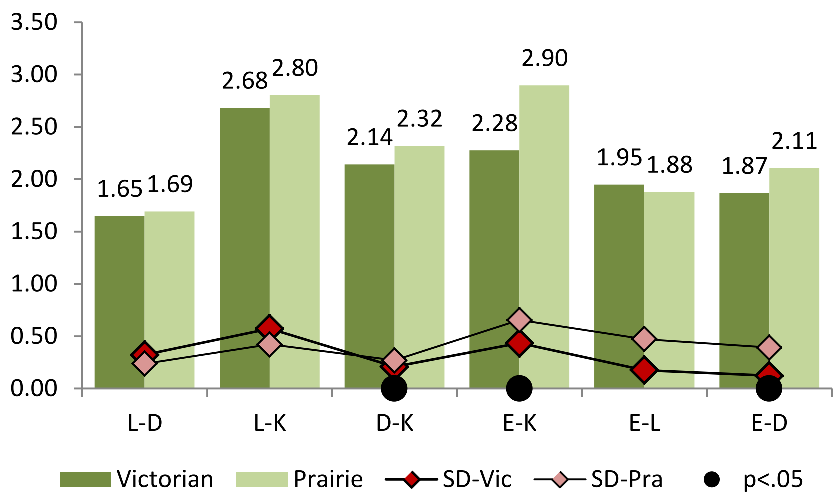


Figure 5.10. The step interspatial depth between the four selected spaces.

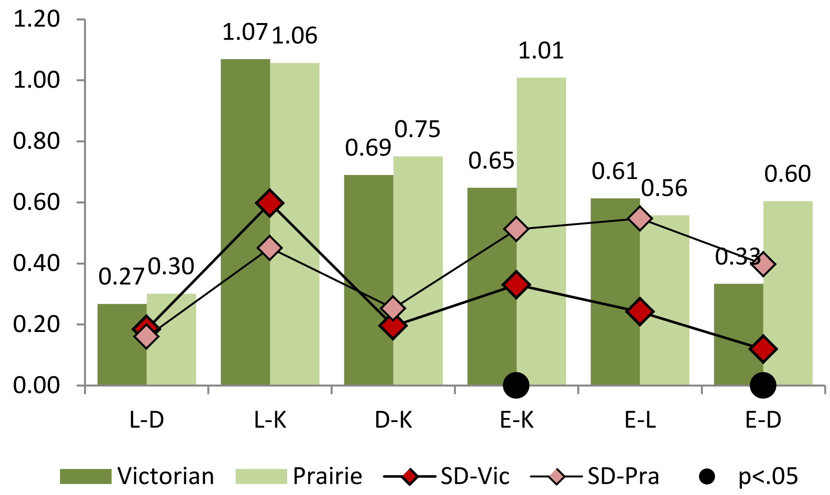


Figure 5.11. The angular interspatial depth between the four selected spaces.

The results show significant differences (black circles on the X-axis) between the two styles in the visual depth from entry to the kitchen (E-K) and dining room (E-D). In both measures, Prairie houses have visibly higher depth, although in the angular variant of both depths, the standard deviation for Prairie houses is very high. This indicates that on average, the food axis of the Prairie house is more secured from the eyes of a visitor, so performing a better design if this segregation was a cultural virtue of that era. Another difference between the two styles is the slightly higher kitchen-dining room step depth (D-K) in Prairie houses which also points to a higher segregation of the food axis. On the other hand, there is no significant difference between the values of L-D connection. Considering the significance of this connection, the lack of difference may remind us that the higher visual connection between the Prairie spaces is not supported in the context of this research.

Considering higher E-D and E-K depths as two features of the Prairie style, The first scheme (#1) of Adams show higher angular and step E-D and E-K depths (see Tables II.21 and II.22 in Appendix II). Meanwhile houses for Sutton (scheme #3) and Waller show only higher angular depth values and houses for Little and May feature only higher step depths for E-K and E-D depths. On the other hand, houses for Fuller, Kellogg and Ross feature the lowest E-K and E-D depths (both angular and step) making them closer to the Victorian average. The houses for Martin, Baker and Stockman (for angular depth) houses for Adams, Baker and Little (for step depth) are also closest to the average of the Prairie houses.

Both styles also show some similarities in the order of interspatial depths. In both styles, the depth between the dining and living (parlour) rooms (L-D) is the lowest depth between all measured spaces by both angular and step depths. Similarly, the visual depth between kitchen and living room or parlour (L-K) is almost the highest in both styles, reflecting the undesirability of this connection.

In contrast, based on Figures 5.10 and 5.11, there seems to be a significant difference in the orders of E-K and E-D between the two styles. In the Victorian houses, the L-K solely has the highest depth in both measures while in the Prairie houses, the E-K depth seemingly competes with it (88% of Victorian houses have L-K > E-K, while this figure is only 50% for Prairie houses). A probable reason for this difference is that most of Prairie houses feature a separate entry to the service area. Therefore, there is no need to (or there are reasons not to) bring the main entry and the “messy” service area closer.

Similarly, the E-D depth in the Victorian houses is the second-least depth, while it is more towards the middle of the order in the Prairie houses. Hence it is possible to draw an approximate sequence of interspatial depths for both styles. First, the sequence for Victorian houses is presented. An issue for finding a sequence is that half of the measures were related to the entry space, which is not present in 40% of the Victorian samples. Therefore, the sequences with the entry (E) will only be sought for houses which contain this space. Sequences 5.12 and 5.13 show two assumed orders of connections with and without entry (the algebra is based on the degree of connection that is the reverse of depth values shown in the figures). The occurrence of the first sequence is 67% and 89% for step and angular depths, respectively, while the second sequence is present in 86% and 53% of the houses for the step and angular depths. While these sequences separately show a common presence in the houses, any combination of them significantly decreases their prevalence.

(5.12)

E-D < E-L < E-K

(5.13)

L-D < D-K < L-K

Prairie houses show the same sequence (5.13) for the non-entry connections with its occurrence in 74% and 66% of Prairie houses, in step and angular measures respectively. On the other hand, as reported earlier, there is a shift in the order of E-D and E-L depths (Sequence 5.14). This sequence is present in 74% and 45% of Prairie houses in respective step and angular measures.

(5.14)

E-L < E-D < E-K

The latter difference between the two styles (in Sequences 5.12 and 5.14) does not necessarily suggest a functional difference between the styles' dining rooms. This difference can be explained by the geographic relationship between the entry and the two spaces. In the selected Victorian houses, it is common to locate both entry and parlour closer to the main façade of the building while the dining room is usually at rear. Considering both parlour and dining room are connected to the hall by sides, it implies that the visitor should turn 90° to enter the parlour while they can move straight to the dining room (Figure 5.12).

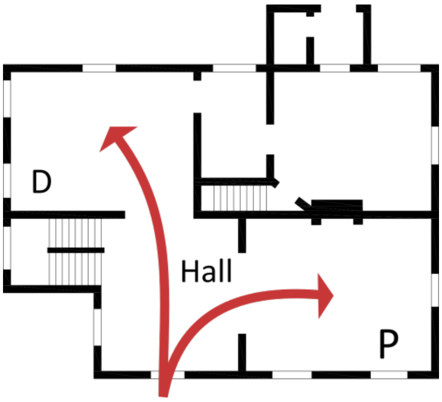


Figure 5.12. An example of the location of parlour (P) and dining room (D) compared to entrance direction in the Victorian houses (plan adopted from Cirker, 1996).

In conclusion, the results support the premise of undesirability of connections (both visual and access) between social and service areas of the house. However, the Prairie houses succeed in attaining another level of this segregation by increasing the visual distance between the entry and kitchen. Nevertheless, it is worth reiterating that the usefulness of the interspatial measures in this section is theoretical, and so the results of this measure are not to be treated with the same certainty as others.

5.8. Spaces crossed by axial lines

In the methodology section (4.4.9), two approaches for primal axial mapping were considered in the analysis, including highly-integrated axial lines (HIALs) and the spaces crossed by them.

For the first approach, the most frequent highly integrated axial lines (HIAL) were recorded (for the definition of HIALs see 4.4.9). Figure 5.13 and Table 5.2 show the percentage of houses in both styles which feature these HIALs. The axial lines are labelled with the acronyms of the spaces they cross, separated by “x” (L: living room, D: dining room, K: kitchen, H: hall and S: any space in the service zone. The last label only captures the important axial lines between living room and the service zone. This particular axis is important because of its undesirability. In addition, DxL also includes DxHxL).

Although there is no statistical significance in the difference between the two styles (p-value > 0.05 in Table 5.2), the difference between the two styles in the axial lines between the dining and living rooms is curious. This suggests the possibility of a higher importance of the visual relationship between these two spaces in Prairie houses.

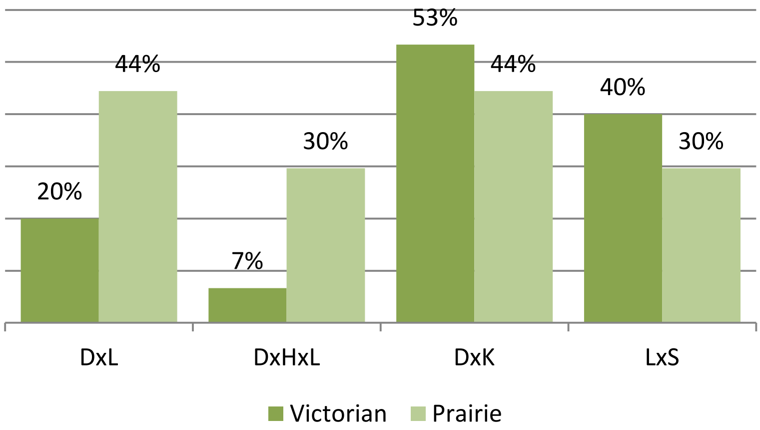


Figure 5.13. The most common axial lines with highest integrations (HIAL).

Table 5.2. The percentage of houses with a certain HIAL.

Styles	**Lines**				
	DxL	**DxHxL**	**DxK**	**SxL**	**N/A**
Victorian	20%	7%	53%	40%	13%
Prairie	44%	30%	44%	30%	30%
p-value	0.080	0.075	0.218	0.210	0.158

The second approach in this section compares the spaces which are crossed through their centre by the HIALs (for clarification see 4.4.9). Figure 5.14 shows the percentage of houses in which the major spaces are crossed by an HIAL. The statistical significance of observable differences ($p < 0.05$) are indicated by black circles on the X-axis.

There are two major differences between the two styles. Firstly, it appears that there are higher percentages of the HIALs in Prairie houses. This may indicate more connectivity between the spaces, which lead to a higher number of HIALs. Secondly, the Prairie living room, dining room, and entry play a more significant role in defining the visual axes of the house, especially compared to the kitchen. These two differences may imply a degree of support for the second claim – *more visually integrated Prairie spaces*. However, one should be cautious because axial mapping is very dependent on geometrical details which are usually more abundant in Prairie houses.

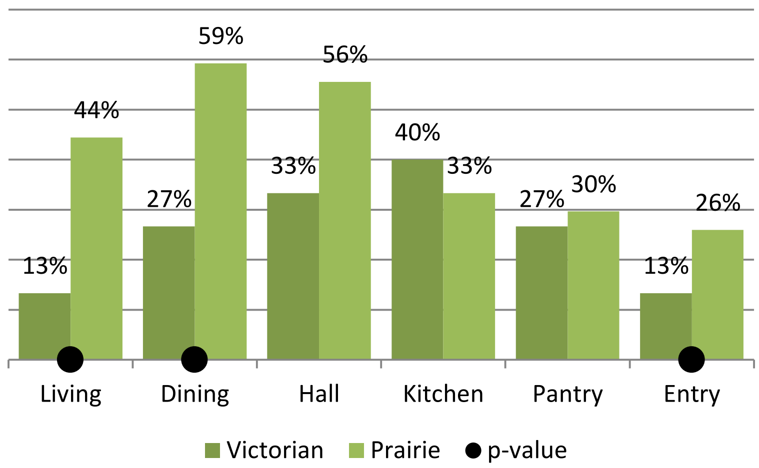


Figure 5.14. The percentage of houses in which a certain space is crossed thoroughly (inside) by an HIAL.

5.9. Summary

The chapter has pursued two objectives. The first objective is to examine a number of spatial properties (or innovations) in Wright's Prairie houses in comparison to those of Victorian houses, using space syntax techniques to provide quantitative measures. The second objective is to identify other similarities or differences between the Prairie and Victorian houses.

Regarding the first objective, the results of the five studies were generally mixed in terms of the five hypotheses framed previously.

- The first set of hypotheses concerning wholeness states that *mean levels of holistic measures will be higher in the Prairie houses than in the Victorian*. This position was not supported by the measured holistic values. However, the results for two of the other claims (spatial isolation and inwardness) suggested that a sense of holistic space may be visually present in the Prairie house, because of the focal status of the highly visually-integrated hall and syntactically because of higher integration of the social spaces. Thus, this hypothesis is rejected as it stands, but alternative evidence has been uncovered which might support the broad intent of the claim.

- The second set of hypotheses holds that *spaces in the Prairie house should be, on average, less visually isolated than in the Victorian*. The position was only supported for one specific space – the hall – in one of the measures. On the other hand, the results suggested that other spaces are more integrated in Victorian houses than in the Prairie houses. Taking into account these inconsistencies, no clear support for the hypotheses has been found.
- The next hypothesis states that *spaces in the Prairie house should be, on average, more inwardly focused than in the Victorian.* While this position was refuted by the exterior-interior comparison, it was partly supported by considering the ranking of integration values. Regarding the implication of the hypothesis that this property brings the family together, the latter process (ranking of integration) appears to be a more suitable measure.
- Fourthly, historians maintain that the *Prairie house plan should possess a greater degree of circularity than the Victorian*. This hypothesis was generally supported by the results. However, contrary to some of finer-scale aspects of this claim, the rings in Prairie houses were less likely to include living areas (living room, dining room, or hall).
- Finally, the results supported the hypothesis that both Victorian and Prairie houses clearly segregated the social and service areas. Arguably, the Prairie houses were more successful in this matter.

In summary, three of the claims (circularity, inwardness, and spatial segregation) were fully supported by the results while the support for two others (wholeness and visual integration of spaces) was either partial or completely lacking. However, this research has identified several additional dimensions and considerations which were not addressed by the measurements and require more in-depth analysis. Notwithstanding these new observations, all of the results demonstrated that the spatial properties of the Prairie houses are not as unprecedented in Victorian houses as some historians maintain and, in fact, the topological features of the two design approaches resemble each other in some regards. This would suggest that while the spatial innovations of the Prairie style are worth discussing, their continuation of the previous topological organisation is also notable, especially when the drastic changes in forms and layouts are considered.

For the second objective of this chapter, the results can be summarised as below:

- Prairie houses differ from Victorian houses in the portion of the house dedicated to the living room and entry (both are larger in Prairie houses) and the kitchen (larger in Victorian houses).
- The difference in the relatively larger living room apparently affect some of the visual properties of its usually adjacent space (hall, dining room, and entry).
- Despite the different proportion of spaces, the average houses of both styles show similar holistic visual features.
- Victorian and Prairie houses possess a more or less similar order of spaces based on their visual properties (isovist area, step mean depth, and angular mean depth). This order can be abstracted to:
  (hall) > dining room > living room > kitchen.
- Victorian houses show more uniformity in the order of the major spaces regarding their convex-based integration values. The most prevailing sequence of spaces in these houses are:
  (hall) > dining room ~ kitchen > living room > (entry)
- Prairie houses are more diverse in order, showing the possibility of multiple genotypes.
- The results suggest that the visual connection between the entry and dining room is higher in Victorian houses, although this is a consequence of the placement of the spaces. Nevertheless, this may indicate that the "diagonal plan" of the Prairie houses may not contribute to more visual connection, if it is interpreted in the context of space syntax.

- Both styles show two common visual orders in the connection between spaces. Considering the three main "squares" of the house (kitchen, dining, and living rooms), the order of their connections to each other was as follows:
  D-L < D-K < L-K
- However, the two styles differ in the order of connections of the three main "squares" to the entry. While in both styles the E-K connection is the most distant, the E-D connection is highest in the Victorian houses but second in the Prairie samples.

This chapter has also identified Prairie houses which feature more Prairie characteristics. Table 5.3 shows the summary of the identified houses. In this table, the black square (■) represent the "Prairie-like" houses, the blank squares (□) indicate the representativeness, and the crosses (x) represent the "Victorian-like" houses. As is seen, there is no house that features a majority of the claims, or can be considered a representative of the style in most measures.

In conclusion, this chapter identifies a number of similarities and differences between Victorian and Prairie houses. However, the focus of this chapter is the Prairie house, disregarding the differences between the houses of the styles. To address this issue, the next three chapters (6, 7 and 8) analyse the Prairie houses based on their variation of layout features including the types, subtypes, and service connections.

Table 5.3. The Prairie houses based on how they are compared to the claims and average values (the grey shade is only for a better legibility of the table).

	Measures							
House	Size	Holistic	IA (hall)	SMD	AMD	Inward.	SID	AID
$5000					□[1,2]			
Adams								□
Adams #1	■			□[1]			■	■
Adams #2			■					
Baker	■				□[2]	■	□	□
Baldwin								
Barnes			■					
Brown				□[1]				
DeRhodes								
Fuller	x	■				■	x	x
Gale		□						
Kellogg	x						x	x
Larwill		■		□[2]				
Little								□
Little #1								
Martin		■		□[2]			□	
May							■	
Millard	■							
Nicholas		□						
Roberts	x	■		□[1,2]	□[1,2]			
Ross							x	x
Stockman					□[1]		□	
Sutton #1								
Sutton #3							■	■
Waller								■
Walser			■					
Ziegler								

[1] considering all six major spaces
[2] considering the larger spaces (living and dining rooms, kitchen and hall)

6. Convex mapping measures

6.1. Introduction

In Chapter 2 a general outline of formal and spatial properties of Prairie houses was presented, including a typology proposed by Pinnell (2005) for simple Prairie houses based on the position of the four "squares" and the fireplace (Section 2.4.1). Chapter 5 has presented a detailed measurement of several spatial properties in Prairie houses collectively, disregarding their types (as the purpose of that chapter was to compare them with the houses of the Victorian era). The results of the latter chapter showed several similarities and differences between the spatial properties of Victorian and Prairie houses. However, considering that the focus of the previous chapter was on the *average* of all Prairie houses, it was not clear how the different or similar features are distributed among the Prairie houses, especially in regard to their variations of layout. The present chapter investigates the relationship between the layouts of the houses (mainly regarding the proposed typology) and their convex-based topological properties.

As explained in the research design (Section 4.3.3), Prairie houses were categorised into two types and six subtypes based on the typology proposed by Pinnell (2005). The aim of this chapter is to understand whether and how the types and subtypes affect the spatial properties of the houses, or in other words, to what degree the formal typology is representative of the topological properties of the houses. Nonetheless, this chapter only focuses on the organisational aspects of topology, that is, the convex mapping approach of the space syntax theory. The other two approaches (visibility graph and axial mapping) are discussed in the next two chapters, respectively.

The chapter includes four analysis sections. The first section (6.2) discusses the results for the holistic measure of intelligibility. Section 6.3 presents the results of the integration values. The next section (6.4) analyses the inwardness of spaces across the houses. Finally, the presence of rings are compared in the layouts.

6.2. Intelligibility

Intelligibility is the correlation between the respective global and local measures of integration and connectivity (Hillier, Hanson & Graham, 1987). It reveals the clarity of the spatial organisation of the building. In this research, this measure was analysed by comparing it against the service connections and subtypes of Prairie houses. Figures 6.1 shows the intelligibility values for the houses based on the presence of service connections, and Figure 6.2 shows this measure for the houses of different subtypes. In these figures the significance (p < 0.05) is indicated by a black circle on the X-axis. For the connection pair ("yes" and "no") one black circle represents the significance of their differences.

The results in Figure 6.1 suggest that only the hall-service connection has a meaningful effect on the intelligibility values (0.91 versus 0.84), although caution is necessary in analysing this finding because of the very high levels of intelligibility. In the previous chapter, it was discussed that the hall might have been crucial for understanding the whole of the Prairie house. The finding of this study supports this implication as the intelligibility is affected by the relationship between the hall and another space. On the other hand, there is no significant difference observed in the intelligibility of the subtypes in Figure 6.2.

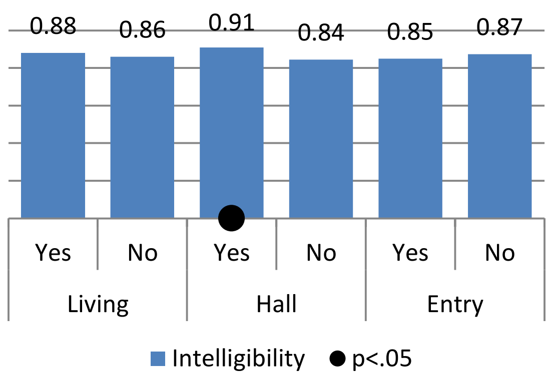


Figure 6.1. The convex intelligibility of Prairie houses based on service connections (the connected spaces are marked).

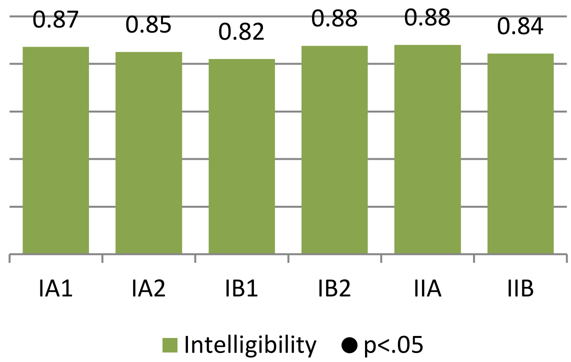


Figure 6.2. The convex intelligibility of Prairie houses based on the subtypes.

6.3. Integration

The integration value indicates the degree by which a space is accessible from other spaces in the house, or in other words, integrated into the house (see 3.3.1). It also, in counterpoint, indicates how that space would access the rest of the house. In this section two approaches to integration values are discussed. First, the prevalence of certain ranks (ordinal scale) of the integration values are presented. In the second approach, the sequence of the spaces based on the integration values are discussed. In both approaches, the integration values and ranks of the major spaces are studied based on the types, subtypes, and service connections in the Prairie houses. Moreover, the results for each subtype and service connection are also compared to those of Victorian houses in order to obtain a more thorough understanding of the position of each subtype in the architectural context of that era.

6.3.1. Ordinal ranking of the integration values

The goal of ordinal rankings is to provide a picture of the position of various spaces in the spatial organisation of the whole house. In the previous chapter (see Section 5.5.1, particularly Figure 5.7) an overall ranking of the integration values was provided. In summary, the hall and dining room were often the top two integrated spaces in Prairie houses, followed by the living room and the rest of the spaces. However, this order was not always present in the Prairie houses, suggesting that there are several factors influencing integration values.

In this subsection, two groups of hypotheses are considered for explaining the differences in the integration values and rankings. The first set pertains to the effect of the service connections on the integration values. The second group of hypotheses focuses on the possible influence of the subtypes on the results. The service connections are considered first because their connective nature is more important in convex mapping than their geography (subtypes).

Hypothesis group I

As mentioned in 4.3.3, the presence of service connections influences the connectivity of the spaces in the service zone, and so influences the formation of the convex maps. In this regard, a number of hypotheses are considered based on the effect of these connections upon the integration of spaces, especially the kitchen and dining room:

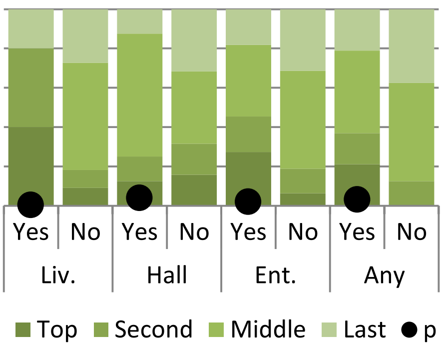
a. Considering that the depth between the kitchen and social spaces may be reduced in the presence of a service connection, there will be a higher integration rank for the kitchen (and to a lower degree pantry).
b. In contrast, the integration rank for the dining room would be lower in the presence of a service connection, because it no longer monopolises the access to the service zone.
c. In the presence of a service connection with a space, the integration of that space will be higher compared to when this connection is absent. However, this does not necessitate a difference in the integration values for the kitchen, as the absence of *one* connection is not equal to the absence of *any* connection.

Results I

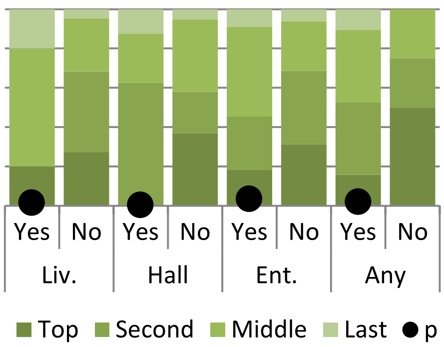
Figure 6.3 shows the ordinal integration based on the connections between the three spaces and the service area (see the part (c) of subsection 4.6.2 for the guidelines on the visualisations). The black circle indicates cases where there is a significant difference ($p < 0.05$) in the integration values between when the connection is present and absent; there is only one indicator of significance (black circle) for each pair of presence-absence ("yes" and "no") of the service connections. The horizontal gridline on the graph represents a 20% increment.

As predicted, the existence of connections between the service area and the three selected major spaces has a clear effect on the integration of all spaces (except the hall). Regarding the first hypothesis (a), the existence of a service connection also generally increases the prominence of the kitchen in the house. The only exception is the hall-service connection in which the opposite apparently occurs. This exception may be because of the central position of the hall which increases the integration of all connected spaces to the hall simultaneously.

The second hypothesis (b) is also supported as the dining room is significantly less integrated when there is a service connection present. The connections of the hall and living room to the service zone also tend to shift the organisational centre of the houses (i.e. first ranked integration) from the dining room to those spaces respectively. As expected from the third hypothesis (c), the integration rank of all three spaces is significantly higher when they are connected to the service zone.



Living room



Dining room

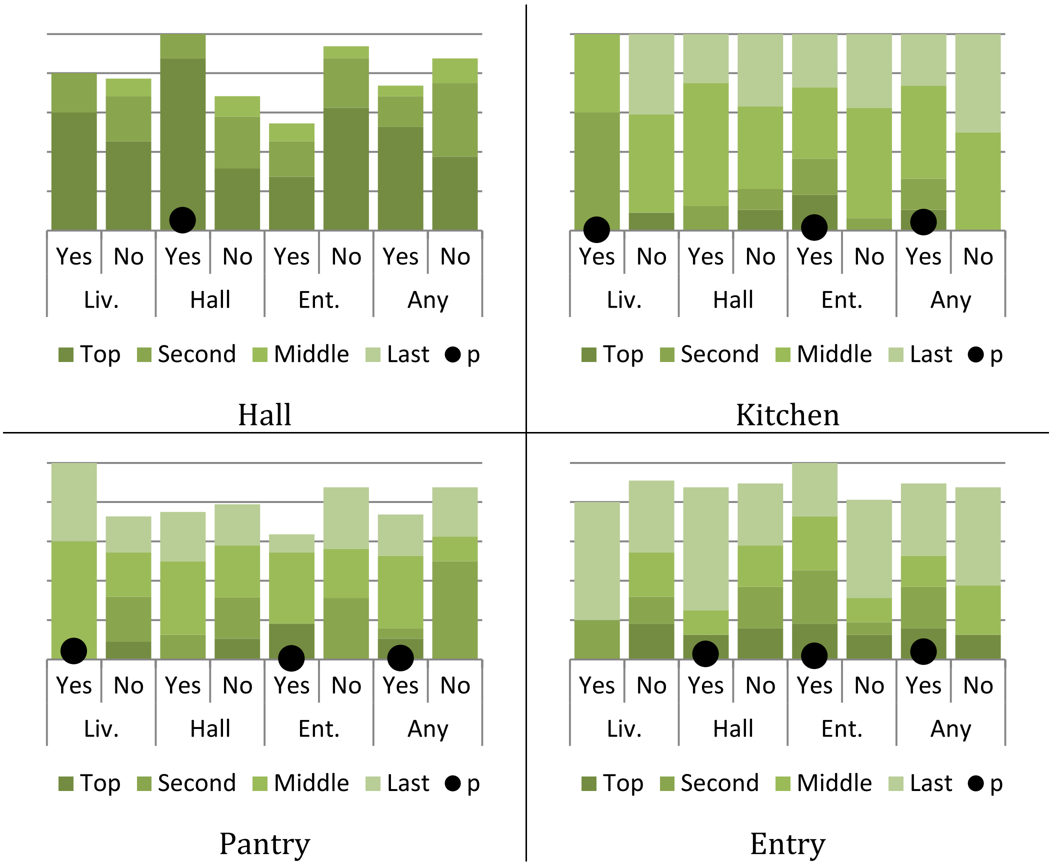


Figure 6.3. The average ordinal integration values of the dining room, entry, and kitchen based on service connections.

An interesting point which is not covered by the three hypotheses is the effect of the service connection with one space on the other two spaces. As mentioned, the hall is not significantly affected by any of the connections. This may be because the hall is already a high-ranking space in the house without the connection. However, the hall-service connection affects both living room and entry. For the living room this effect is mixed (increasing both first and last-ranked). For the entry, the existence of a hall connection decreases the integration of the entry. These effects are not necessarily due to a separate configurational pattern of these spaces but because of the combination of the service connections. In most houses, there is only one connection present. This means that if there is a hall-service connection, there will be a higher chance for the absence of an entry-service connection.

Hypothesis group II

In section 4.3.3, part (b), the presence of service connections in subtypes was discussed. In summary, there were more connections in Type II (especially

Subtype IIA) than in Type I. Considering the effect of service connections on the integration values, it is assumed that these effects are also reflected in the types and subtypes. In this regard, the second group of hypotheses are formed (numbering is continued from Hypothesis group I):

d. In type I, and specifically, subtypes IA2, IB1 and IB2 (without many service connections – see Figure 4.4) the dining room would be the main space which is connected to the service area. This may make the dining room a central space in the house (which mediates between the service area and the living areas) while rendering the service area (kitchen) an isolated space. Therefore, we expect a relatively higher integration rank and value for the dining room and lower integration rank for the kitchen and pantry.
e. Considering that there is no entry-service connection in the above three subtypes, the entry's integration in these subtypes would be lower than in the other houses.
f. Subtype IA1 would be an exception in Type I houses, as there are several houses with a service connection. Therefore, the dining room is less focal in the organisation of the houses.
g. In contrast, in type II, particularly subtype IIA, there is more opportunity for the service area to be also connected to the rest of the house through the entry. In this case, the dining room would not have the same importance as in type I, while the kitchen and pantry would be more integrated into the house.

Results II

The results are shown in two levels, by types (Figure 6.4) and by subtypes (Figure 6.5). In both figures the darker colours indicate the higher integration ranks in the four-step scale (first, second, middle, and last).

The results shown in Figure 6.4 support the hypotheses (d) and (g) as there are more *first* (39%) and *second* (33%) ranked dining rooms in type I compared to type II (11% and 22%, respectively) (their significance is shown by black circles on the X-axis). Also, there are significantly more first and second-ranked kitchens in type II as predicted (44% versus 6% in type I).

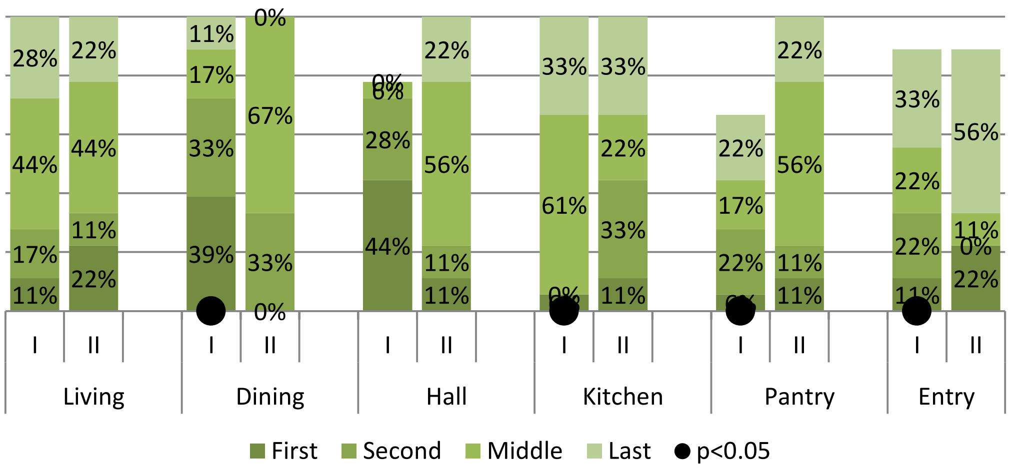


Figure 6.4. The average ordinal integration of major space in types I and II houses.

Figure 6.5 shows the ordinal integration of the major spaces in the six subtypes, where each figure displays the ordinal integration for one space among the six subtypes.

As expected (hypothesis *f*), the dining room in subtype IB2 shows a significant difference to the rest of the houses. The dining rooms in this subtype appear to lean more towards the higher ranks of integration. Supporting hypothesis *g*, the dining room of the subtype IIA features a clear organisational difference from the other dining rooms. It features significantly lower integration values that can be related to the extensive service connections in this subtype. In contrast, the IIA kitchen features a higher rank of integration after being connected to other spaces in this subtype.

Figure 6.5. The ordinal integration of major spaces in Prairie subtypes, displayed based on subtypes.

The living room falls sporadically in different integration orders in subtypes IA1, IB1, IIA and IIB. In subtype IB2, the living rooms have a lower integration (67% *last* and 33% *middle*). The low *p*-value also supports the difference in this subtype. The living room in IA2 features a slightly higher integration order than others. Even though there is a significant difference there, the result should be treated with caution because of the low number of houses in this subtype. In general, apart from the layout of IIA, the second hypothesis remains unattested, therefore suggesting that the difference between the integration values in Prairie houses are less related to their typological differences than to other factors.

The differences of the integration ranks of spaces between the subtypes encourages us to revisit the comparison between Prairie and Victorian houses. Generally, the main difference in the integration rankings between Victorian and Prairie houses was the more prominent living room (and to some extent dining room) in the Prairie style, and more prominent kitchen in the Victorian houses. In this context, if these two differences are to be considered as the respective qualities of "Prairie-ness", then it can be argued that the organisation of the living room in IB2 and the dining room and kitchen in IIA is more Victorian than Prairie.

6.3.2. Sequences of spaces

The results of the previous subsection demonstrated a general ranking of spaces in the houses, in regard to their integration values. In order to have a more detailed picture of rankings, the exact sequence of the spaces in those rankings are analysed in this subsection. In this regard, the most common sequence in the Prairie houses – *dining room > living room > kitchen* – is first studied (see 5.5.2, Sequence 5.11). Figure 6.6 shows the occurrence of this sequence (shortened as D>L>K) in Prairie houses in regard to their subtypes and service connections. The data suggests that there is no significant correlation between the occurrence of this sequence and the subtypes or service connections. However, we can consider a relative significance (p = 0.054) for when the living-service connection exists (0% versus 50%). This further verifies that the living-service connection shifts the organisation of the space.

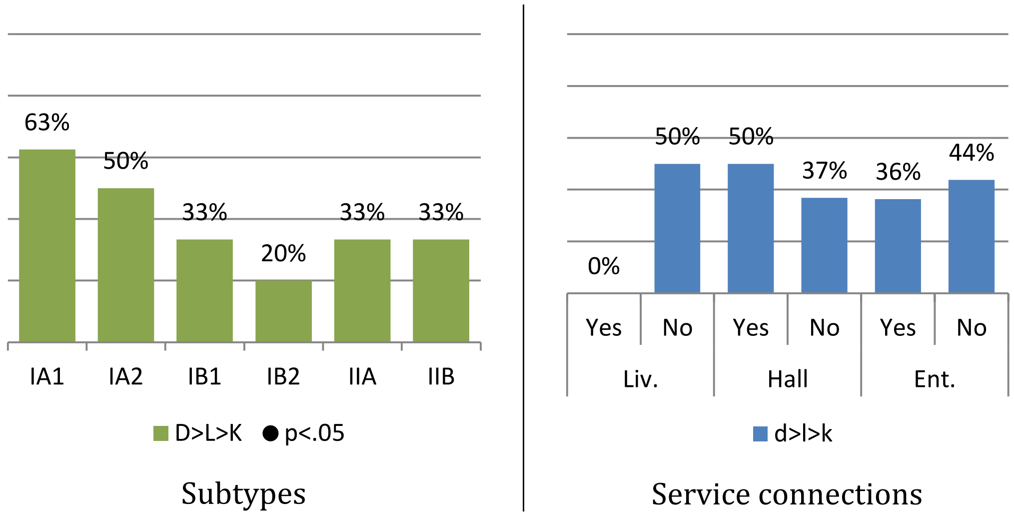


Figure 6.6. The occurrence of the sequence dining room > living room > kitchen (D>L>K) in Prairie houses based on subtypes (left) and service connections (right).

Furthermore, three parts of this sequence (i.e. *dining room > kitchen*, *dining room > living room*, and *living room > kitchen*) are studied in order to shed more light on the effect of service connections and subtypes on the spatial organisation of the house. Figures 6.7. and 6.8 show the occurrence of these three sequences in Prairie houses based on the service connections and subtypes, respectively.

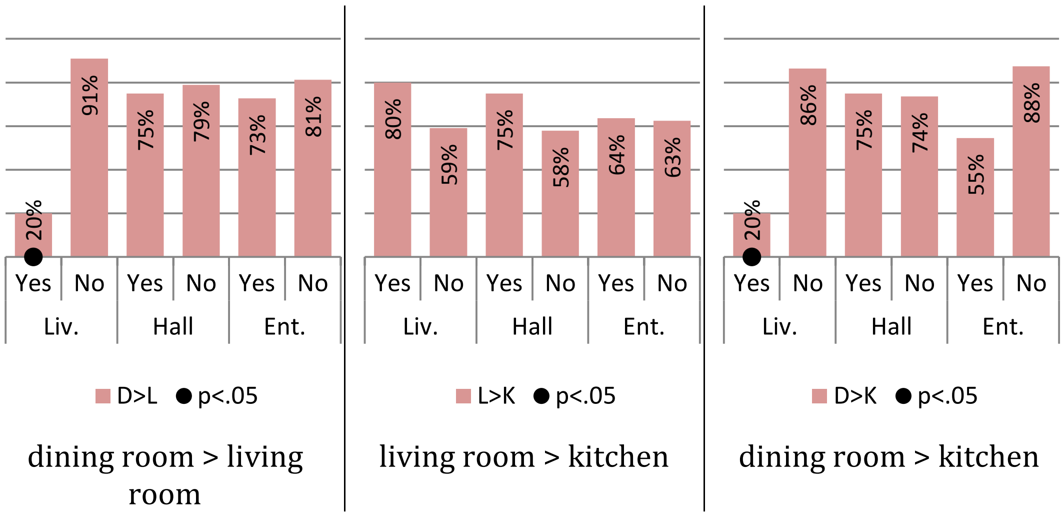


Figure 6.7. The percentage of Prairie houses in which certain sequences of integration orders are present, based on the service connections with living room, hall, or entry.

As expected, the living-service connection changes the organisational importance of the dining room and the hall in favour of kitchen and living room. However, it does not change the dynamic between living room and kitchen significantly. In this regard, the data suggests that there are two "types" of Prairie houses in regard to the integration of the dining room: those with a living-service connection, and those without.

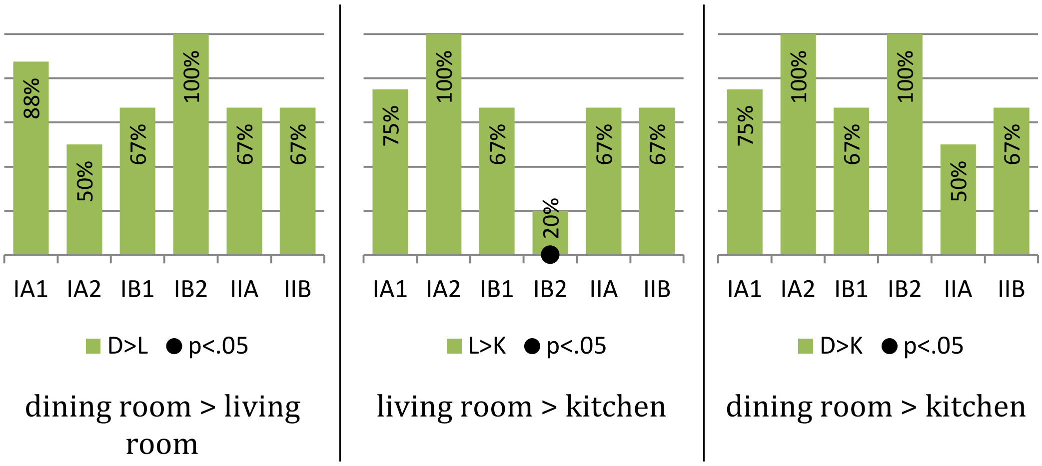


Figure 6.8. The percentage of Prairie houses in which certain sequences of integration orders are present, based on the subtypes.

On the other hand, the differences between the subtypes are not significantly related to the order of dining and living rooms. However, the data reiterates the earlier finding of the less significant living room in IB2 (20% *living room > kitchen*).

Overall, the results suggest that the organisational role of major spaces depends on the existence of a direct connection between the service area and three major spaces including the living room, hall and entry. The spaces which are affected most are the dining room, losing its control over the access to the service area, and the kitchen gaining additional connection to rest of the house. This is reflected in the integration order of these spaces in the subtypes. On the other hand, the results suggest that the types and subtypes have significantly less effect on the integration values compared to the service connection. This further supports the idea that the integration value is less bound to the geometry of the space but to smaller details such as openings.

6.4. Inwardness

One interpretation of "inwardness", as explained in 4.4.3, indicates whether a space is more engaged and integrated within the interior space or whether it is more engaged with the outside. This measure was calculated by comparing the integration values of spaces in two situations: either including the outdoor space in the convex map of the houses, or not including the outdoor space (Hanson, 1998). In this section, this measure of inwardness is studied regarding the types and service connections. A hypothesis is difficult to establish in regard to the types and especially to the service connections. A reason is that while a connection (especially entry-service) reduces the syntactic distance between the kitchen and exterior, it also provides more connections within the internal space and so makes all the systems closer to each other. This was also the problem of interpreting the results in the previous chapter (5.5.1). Therefore, the results are analysed without comparing them against a particular hypothesis.

Results

Figure 6.9 shows the inwardness for the major spaces in the two types of Prairie houses. The results suggest that the kitchen is significantly ($p < 0.05$) more inward in Type II than in Type I, while the dining room of Type II is more outward. These two findings mirror the findings of 6.3.1 (Figure 6.4). The entry appears to be more outward in Type II but this cannot be statistically validated. In general, the findings suggest that although the kitchen is more integrated into the house in Type II, it is also more prone to contact with a visitor; regarding the cultural context this may be interpreted as an organisational issue.

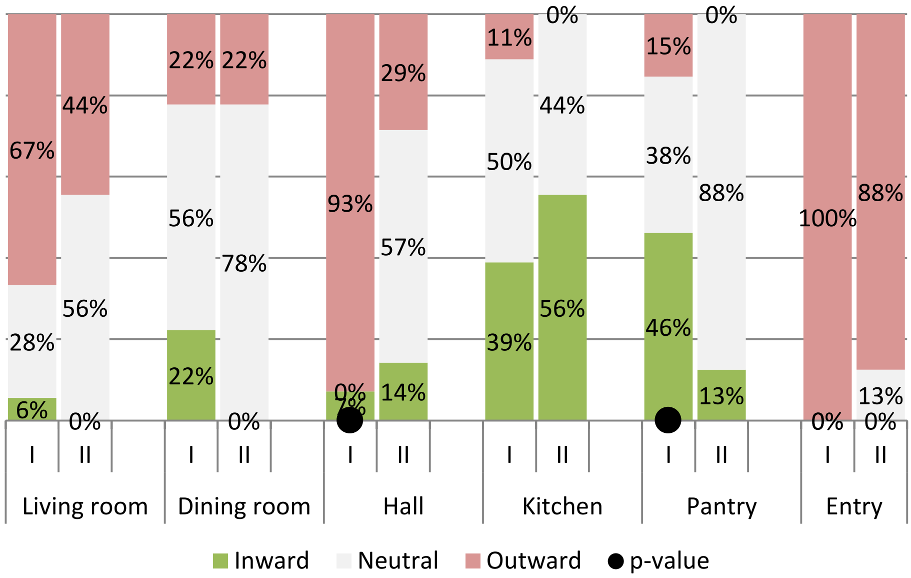


Figure 6.9. The inwardness of major spaces in the Prairie types.

Figures 6.10 to 6.12 illustrate the impact of service connections on the inwardness of spaces. Generally, this measure of inwardness is not evidently affected significantly by the service connections. The only exception is the more inward halls in the presence of the entry-service connection.

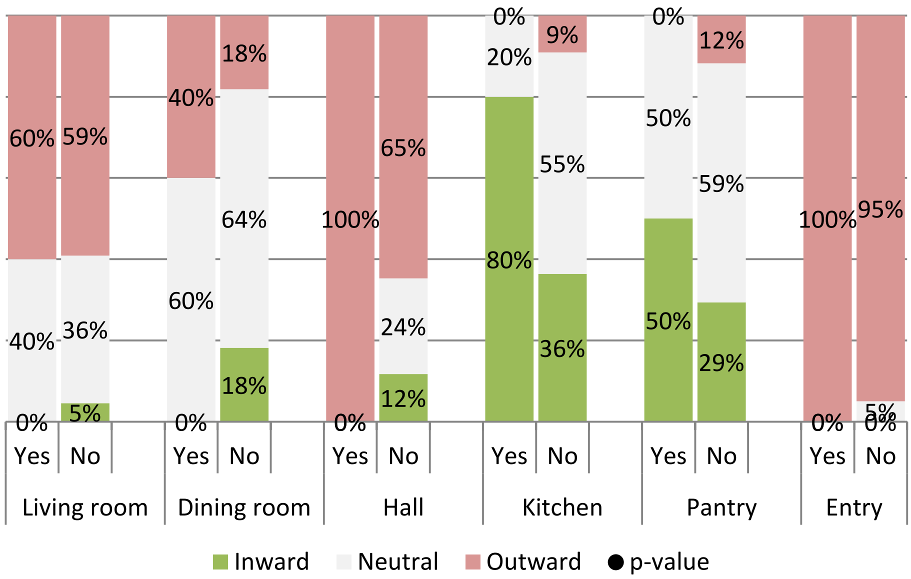


Figure 6.10. The inwardness of major spaces based on the presence of living-service connection.

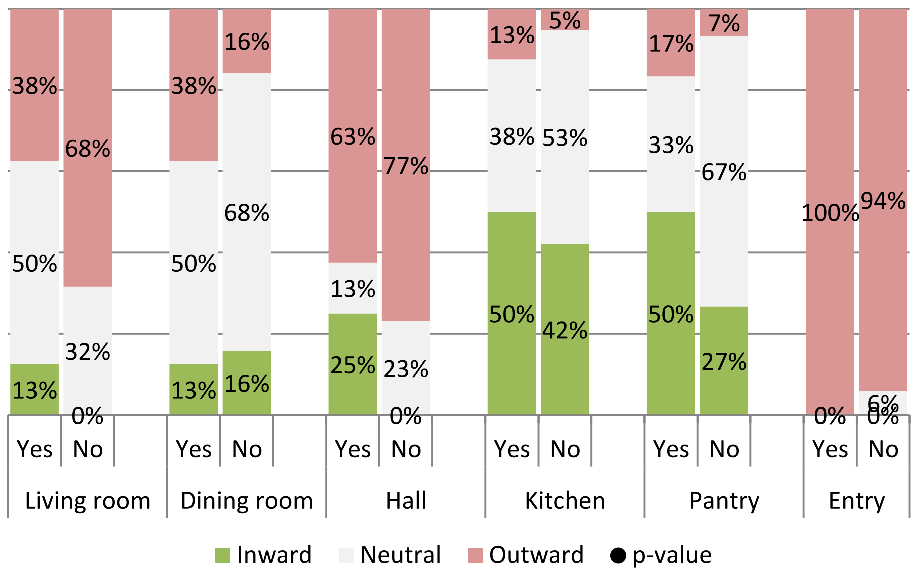


Figure 6.11. The inwardness of major spaces based on the presence of hall-service connection.

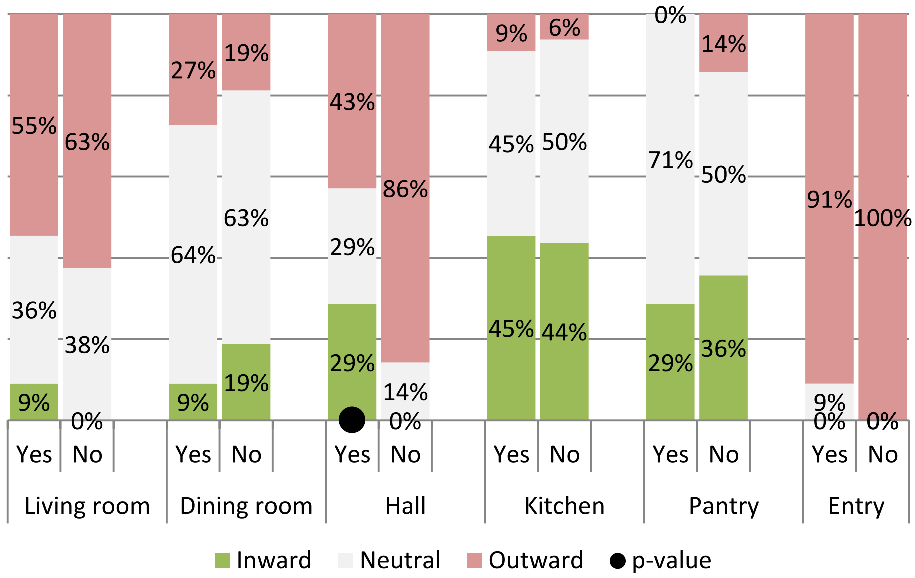


Figure 6.12. The inwardness of major spaces based on the presence of entry-service connection.

Unlike the integration values, the existence of service connections with the living room and entry are not significant factors on the inwardness spaces in the Prairie houses.

6.5. Rings and circularity

A ring is a set of spaces that can be thoroughly passed through while returning to the beginning point in a one-way navigation. Rings are topologically important as they provide alternative circulations within the buildings. As described in the previous chapter (5.6), Prairie houses predominantly feature rings. In this section, the main questions pertain to which spaces are included in the rings, regarding the differences between Prairie layouts.

Hypothesis

Similar to previous sections, a hypothesis is made. The basis of this hypothesis is that the existence of the service connection to the living room, hall or entry assures the existence of a ring in the house. This is because these spaces are already definitely connected to the dining room, directly or indirectly. The connection to the service zone provides an alternative access to the dining room (via the food axis) and makes a loop. So, the hypotheses are:

a. The space connected to the service zone is always included in a ring.
b. The dining room is also included in the rings when there is a service connection. However, considering the high percentage of included dining rooms in rings (Figure 6.13), the difference between houses may not be significant.
c. The subtypes which feature such connections have more of the respective spaces included in the rings. For example, subtypes IA1 and IIA must have more entries in rings as most of their houses (63% and 83%, respectively) have entry-service connections.
d. In subtype IA1 and IIA, the entry is also adjacent to the living room, making the latter on the path to the dining room and so, included in the ring. This means these two subtypes are expected to have more living rooms in the rings.

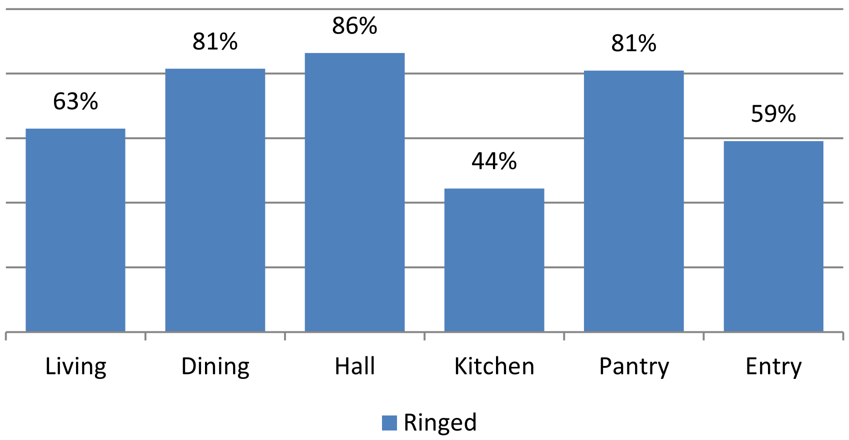


Figure 6.13. The inclusion of major spaces in the rings.

Results

Figures 6.14 to 6.16 show the inclusion of major spaces in the rings when a service connection is present or not. The results largely support the first part (a) of the hypothesis, as 91% and entries and 100% of living rooms and halls are included in the rings when they are connected to the service zone. The second part is fully attested as all dining rooms are included in the rings when there is a service connection. The logic behind the fourth part of the hypothesis (d) can be seen in Figure 6.14, as 82% of living rooms are included in rings when there is an entry-service connection, compared to 50% when there is no such connection.

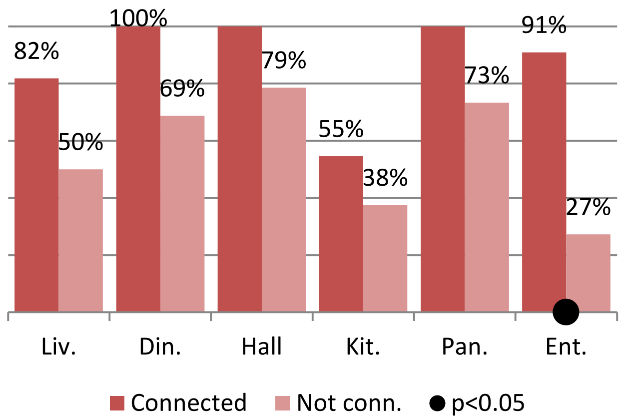


Figure 6.14. The inclusion of major spaces in the rings when the entry is connected or not connected to the service zone.

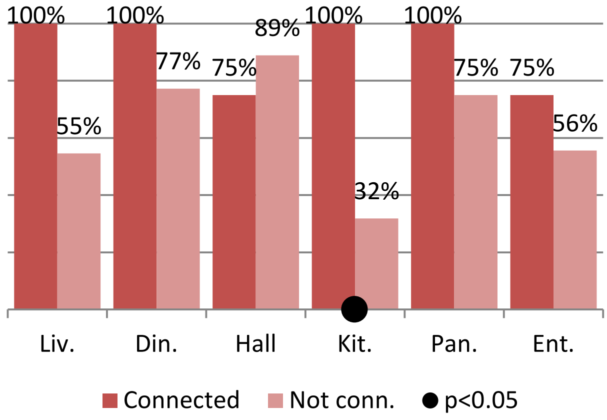


Figure 6.15. The inclusion of major spaces in the rings when the living room is connected or not connected to the service zone.

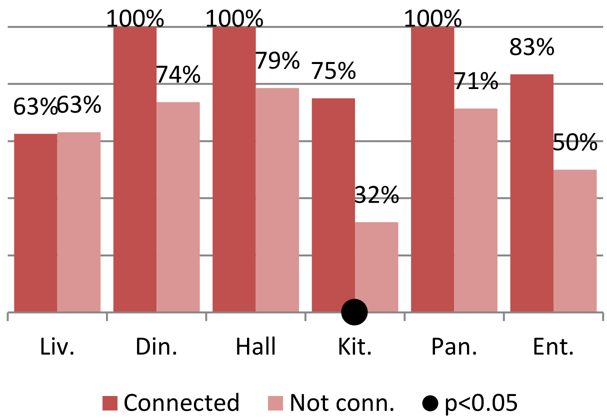


Figure 6.16. The inclusion of major spaces in the rings when the hall is connected or not connected to the service zone.

Figure 6.17 displays the inclusion of the major spaces in rings for the Prairie subtypes. The graphs are separated based on the spaces where their X-axis shows the subtypes.

As expected from the fourth part (d) of the hypothesis, the subtypes IA1 and IIA have the most living rooms (86% and 83%) included in the rings. However, considering the lack of statistical significance, the hypothesis is not fulfilled. On the other hand, the third part of the hypothesis (c) is well demonstrated as the entries of these two subtypes are mostly included in rings (71% and 83%, respectively).

If we disregard the rare subtype IA2, the main differences between the inclusion of the four squares (living and dining rooms, kitchen, and entry) in the rings is the inclusion of more kitchens and entries in IIA and more entries in IA1. The inclusion of more entries in rings seemed to be a feature of the Prairie style (see 5.6, Figure 5.9). Therefore, these two subtypes may be considered "more" Prairie.

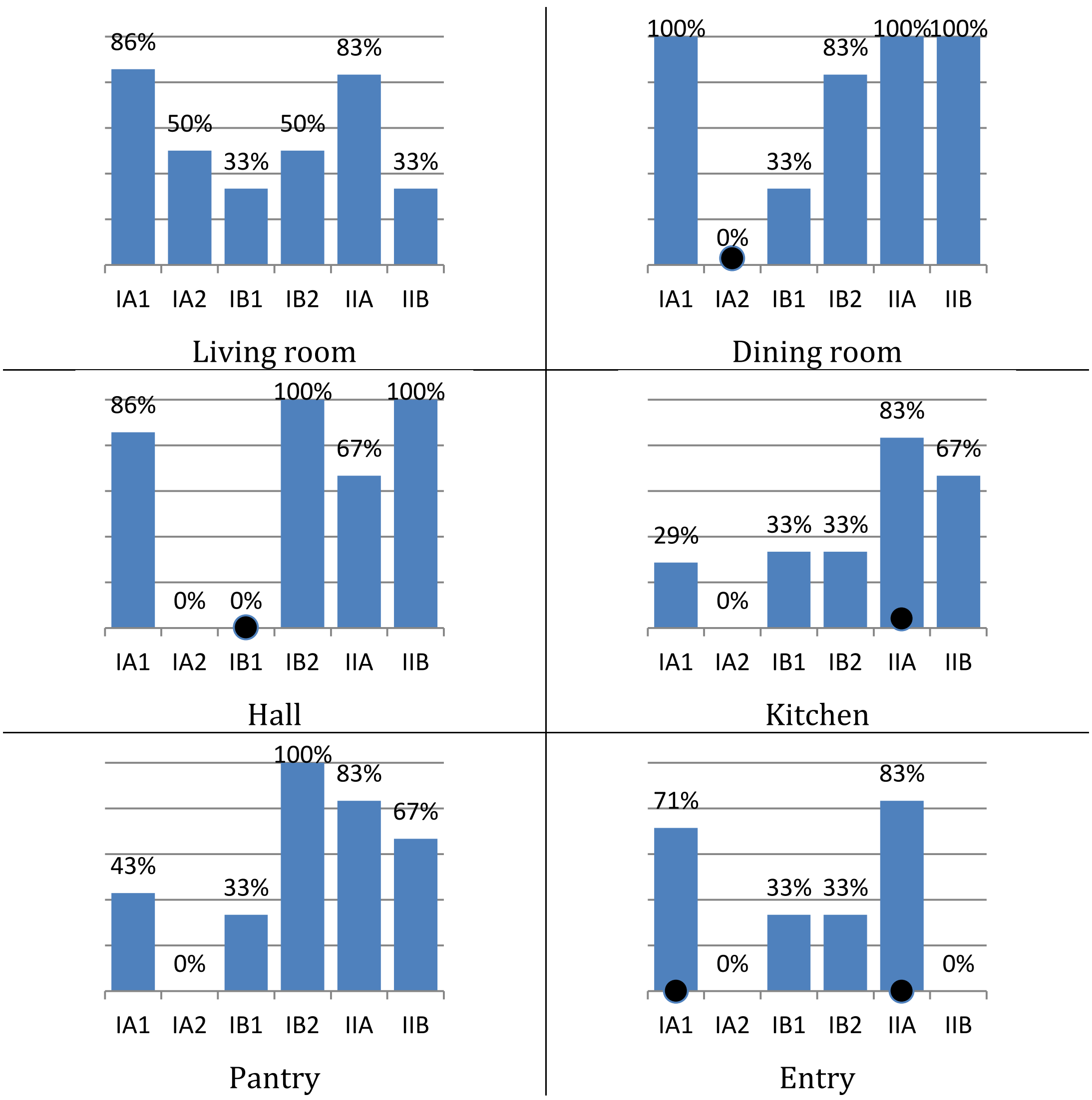


Figure 6.17. The percentage of houses with major spaces in their rings across the subtypes.

Overall, the existence of rings in the subtypes relates to the existence of a second connection to the service area. For individual spaces, their inclusion in rings is also closely related to their connection to the service area. These results support the hypothesis of service connection influence. Regarding the individual subtypes, IA1 and IIA feature a geographical placement of spaces which facilitates the connection of entry and living room to the service area, and thus significantly increases the chance of their inclusion in rings.

6.6. Summary

In this chapter, three measures of convex mapping were applied to Prairie houses. The results showed that the presence of connections of the social spaces (living room, hall, and entry) with the service zone usually had a significant influence on the convex-based measures. Conversely, the layouts (types and subtypes) had only limited effect on the results. However, it was further suggested that the effects of layouts were probably also the result of the presence or absence of connections with the service zone. The differences of the results between types and subtypes could therefore be explained by the abundance of such connections in each type. Nevertheless, these differences manifested themselves only in one or two subtypes for each measure and space, compared to the rest of the measures and spaces.

The relationship between layouts and topological features can be described by two degrees of certainty. First, the presence of some layout features is sufficient for a topological property. For example, the existence of a service connection is sufficient to have the connected space in a ring (Figure 6.13). Another example is the necessity of type II – or precisely subtype IIA – to have a top integrated kitchen and lower rank dining room (Figure 6.4). These relationships are summarised below (we use the verbs like "seem" to indicate the uncertainty, even if the results are certain):

- A Type I layout seemed necessary for a topologically central hall (Figure 6.4).
- A Type II layout seemed necessary for an organisationally prominent kitchen (Figure 6.4).

- Subtype IB1 seemed required for a relatively-isolated living room (Figure 6.5).
- Subtype IIB seemed required for a relatively-isolated dining room (Figure 6.5).
- The connection between living room and service appeared to be sufficient for having a more inward pantry (Figure 6.10).
- The absence of connection between entry and service zone was likely sufficient for an isolated outward kitchen.
- The existence of a service connection seemed sufficient to have the connected space in a ring (Figure 6.10)

The second degree is the higher/lower probability of a topological property in the presence of a layout feature. In summary, the findings include:

- Type I (converse to type II) significantly increased the probability of having a more integrated dining room but a less integrated kitchen (Figure 6.4).
- The existence of an entry-service connection encouraged a higher organisational role of the living room, entry, and kitchen, while making the higher integration of the dining room less probable (Figure 6.3).
- The existence of a living-service connection encouraged a higher organisational role of the living room and kitchen, but had the reverse effect on the integration of the dining room and entry (Figure 6.4).
- Type I layout significantly increased the chance of a more inward dining room and less inward kitchen, while seemingly encouraging the inwardness of entry (Figure 6.9). Obviously, type II had the reverse effect.
- The living-service connection significantly increased the chance of more outward dining room and pantry, while reducing the chance of an inward kitchen (Figure 6.10).
- The entry-service connection increased the chance of a more outward dining room and inward kitchen. (Figure 6.12).

- The subtypes IA1 and IIA increased the chance of the entry being included in a ring (Figure 6.13).
- The subtype IIA encouraged the inclusion of the kitchen in the rings (Figure 6.13).

Another finding in this chapter is that certain features of some of the subtypes lean more towards the average of Victorian houses than to Prairie houses. For example:

- The lower integration of the dining room and the higher integration of the kitchen in the subtype IIA reflected Victorian houses (see 5.5.1, Figure 5.7), while other subtypes showed the opposite position.
- The lower integration of the living room in the subtype IB2 also differed from the Prairie feature of a more integrated living room, aligning more with Victorian houses (see 5.5.1, Figure 5.7).

7. Visibility graph measures

7.1. Introduction

In Chapter 2 a general outline of the formal and spatial properties of Prairie houses has been discussed, including a typology by Pinnell (2005) for simple Prairie houses based on the position of the four "squares" and the fireplace. Furthermore, an alternative clustering of layouts has been proposed in Section 4.3.3 which included smaller-scale decisions based on the connections between the service zone and other major spaces. Hence, the results of Chapter 6 concluded that the service connections are better indicators for predicting the topological properties of space in convex mapping.

This chapter analyses the visual features of the Prairie houses by measures of isovist mapping (or visibility graph analysis). Similar to the previous chapter, both the types and service connections are included in this analysis.

The chapter includes eight further sections. The first section presents the results of holistic measures which may suggest the holistic perception of the space. The second, third, and fourth sections discuss three measures for studying the visual isolation and integration of rooms, including isovist area (or connectivity), step mean depth, and angular mean depth, respectively. Then, two sections (7.6 and 7.7) analyse the interspatial depth (step and angular, respectively) for the main four "squares" of the house. The next section (7.8) focuses on the visual significance and centricity of the Prairie fireplace. Finally, a summary concludes the findings of this section.

7.2. Holistic measures

As discussed in 4.4.1, three of the measures considered for analysing the property of "wholeness" in Prairie houses pertain to isovist mapping. These measures include the average isovist area (or connectivity), and the average angular and step mean depths. These measures were suggested to capture different levels of openness of the whole space. A more open space would have higher connectivity and lower step and angular depths. In this section, the values of these measures are compared against two features of layout, including the subtypes and service connections. The subtypes (and types) are discussed first because both isovist mapping and subtypes share geographical and geometrical features.

7.2.1. Holistic measures and subtypes

Considering the two types and six subtypes of Prairie houses (explained in 2.4.1 and 4.3.3), two possible features may directly affect the results. First, the central position of the fireplace may hinder the direct view between the largest rooms of the house (living and dining rooms), and so reduce the overall connectivity and increases the depth values. Secondly, the relative positioning of the living and dining rooms (opposite or beside each other) may also affect the results. When these two spaces are opposite each other it may be likelier for them to have direct visual connections and so higher connectivity. Therefore, the first group of hypotheses are developed according to these factors.

Hypothesis group I

a. The houses of type II will have a lower connectivity than type I houses because of the side-to-side position of the living and dining rooms.
b. Subtypes IA1 and IB1 would have a lower connectivity than IA2 and IB2 because of their central and hindering fireplace.
c. The same arguments in parts (a) and (b) are reversely valid for angular and step mean depths.

Results I

Figures 7.1 shows, respectively, the average isovist area (IA, in percentage) and step (SMD) and angular (AMD) mean depths, for the two types I and II. In this figure, the black circles on the X-axis represent the validity (significance of $p < 0.05$) of the observable difference between the results. The results support the hypothesis (a) only for one measure (isovist area). The other two measures do not possess a significant difference.

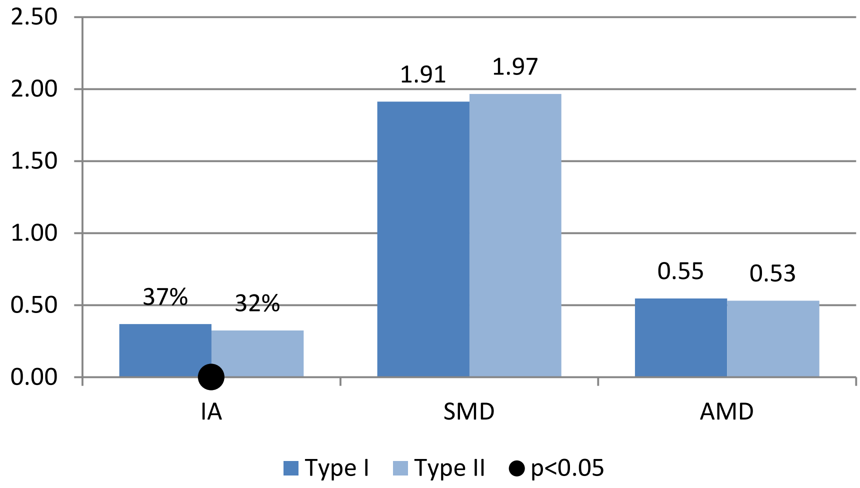


Figure 7.1. Average isovist area (IA) and, step (SMD) and angular (AMD) mean depths, for types I and II.

Figures 7.2 to 7.4 illustrate the results of the three measures, respectively, for the subtypes. In these figures, the dark-coloured diamonds represent the mean value while the light-coloured bar stands for the standard deviation range.

As is expected from the hypothesis (b), the subtypes without a central fireplace (IA2 and IB2) have significantly ($p < 0.05$, shown by black circles) higher isovist areas (43% and $41% respectively). The difference is particularly visible in the contrast between types IB1 (30%) and IB2 (41%). Both subtypes of type II show a lower connectivity compared to IA2 and IB2. In this regard, it is necessary to revisit the hypothesis (a). It is possible that the reason for the difference between the IA values of the two types was mainly related to the position of the fireplace in Type I, not the relative positioning of the living and dining rooms.

Results for the step mean depth (SMD), in Figure 7.2, only show a significant difference in the SMD of subtype IB2. The subtype IB1 also appears to be different from other houses, but because of the high standard deviation in these subtypes the difference is not rendered significant. In any case, the results, at least visually, show some degree of support for the hypothesis (c).

For angular mean depths (Figure 7.3), the results are even more similar for all subtypes. The subtype IB1 still has the highest depth but again it has a very high degree of variance. Ultimately, weighing up these factors, hypothesis (c) has only limited support from the results. In other words, this approach to mean depth cannot be inferred from basic layout differences of subtypes.

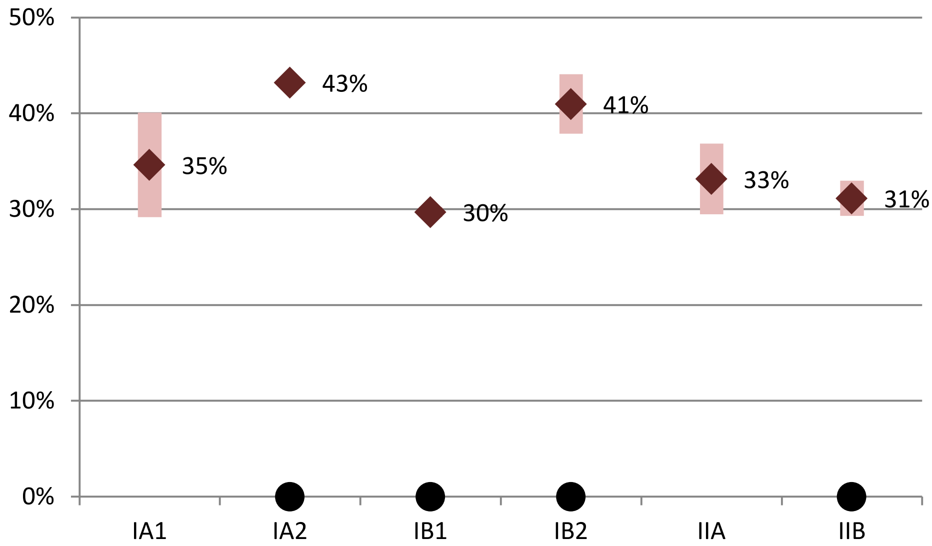


Figure 7.2. Isovist area of the six subtypes.

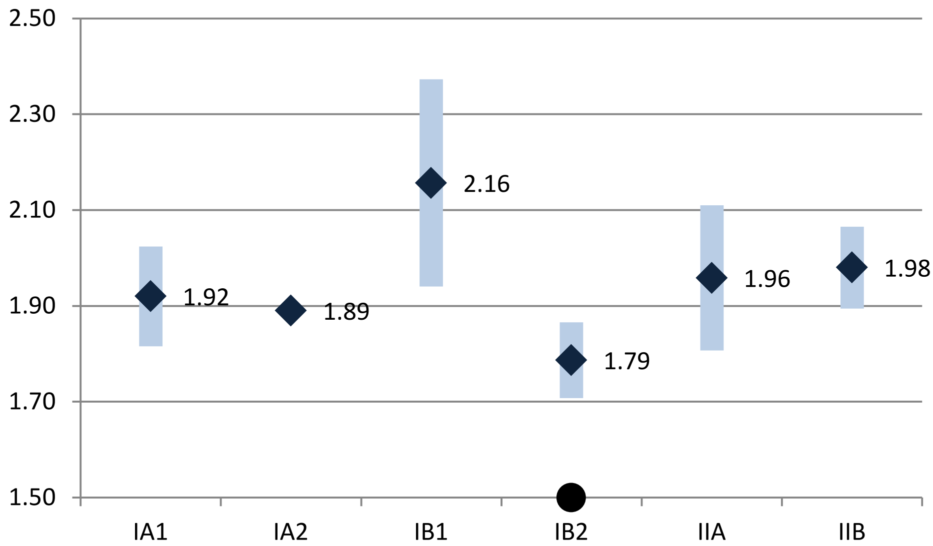


Figure 7.3. Average step mean depth of the six subtypes.

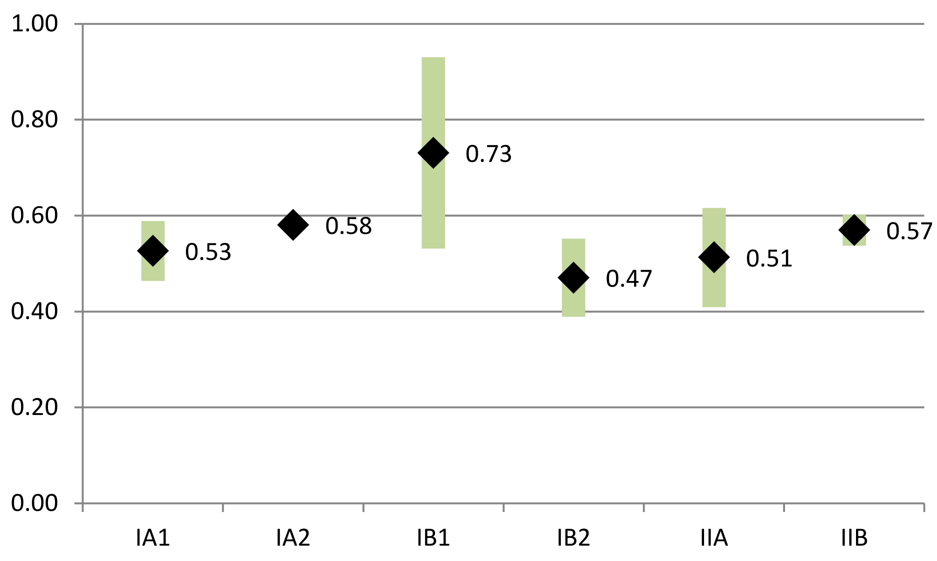


Figure 7.4. Average angular mean depth of the six subtypes.

Results II

Regarding the previous hypothesis group, the main factor affecting the results of the measures was the position of the fireplace. This position is seemingly unrelated to the service connections. Therefore the results are presented without a hypothesis.

Figures 7.5 to 7.7 show the isovist area, and step and angular mean depths of the houses regarding the presence of service connections. The data suggest two significant patterns. First, the existence of a living-service connection reduces the average isovist area of the whole house (Figure 7.5). Second, the existence of an entry-service connection reduces the average angular mean depth of the houses (Figure 7.6). The first finding is somewhat unexpected and remains unexplained. However, the second finding may be explained by the fact that the entry usually has a strong visual connection to the living room (see Figures 5.10 and 5.11), and so an entry-service connection may result in a lower depth between the two sides of entry – living room and kitchen. This may reduce the interspatial connection between the two spaces which are normally the most visually distant in the house (see 5.7, Figures 5.10 and 5.11). Considering the relatively large size of these spaces, a decrease in their visual depth may reduce the average depth in the house.

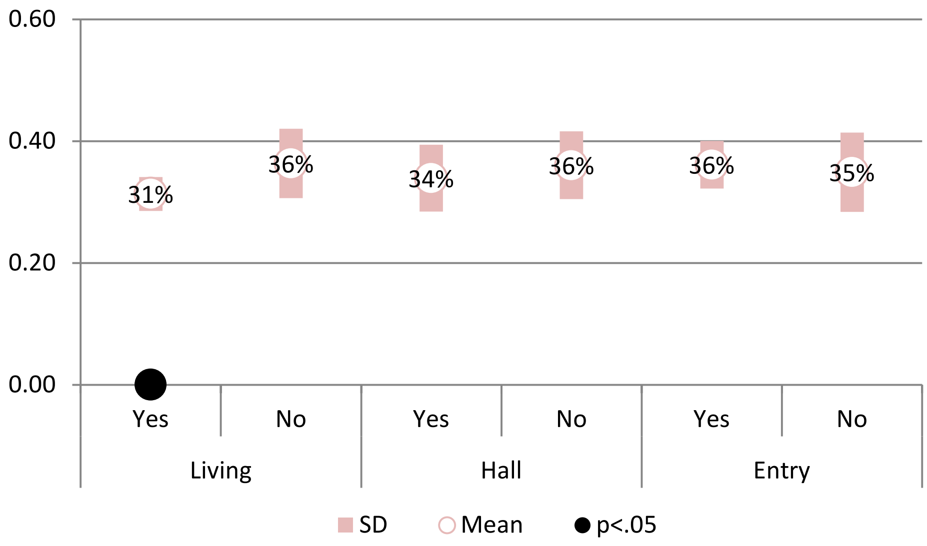


Figure 7.5. The isovist area of Prairie houses based on the presence ("Yes") or absence ("No") of the service connection to a living room, entry, or hall.

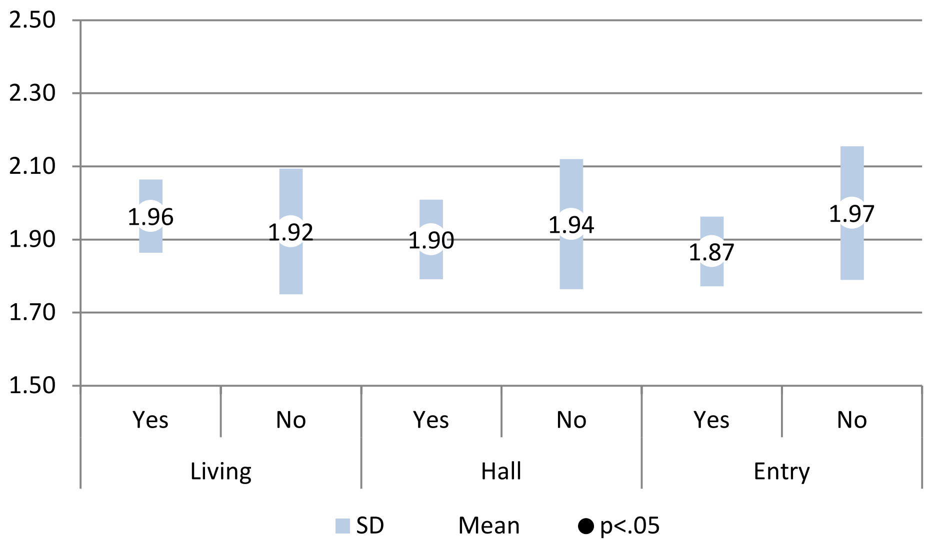


Figure 7.6. The step mean depth of Prairie houses based on the presence ("Yes") or absence ("No") of the service connection to a living room, entry, or hall.

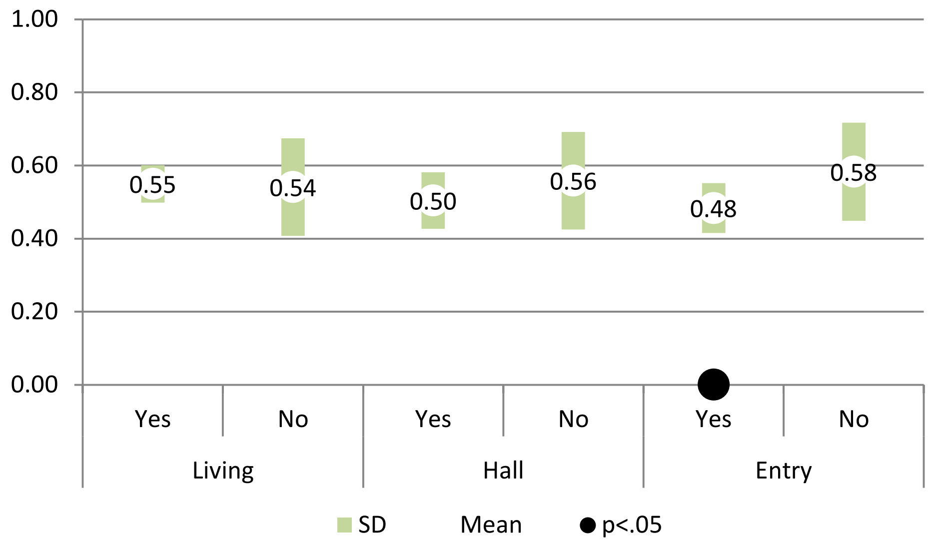


Figure 7.7. The angular mean depth of Prairie houses based on presence ("Yes") or absence ("No") of the service connection to a living room, entry, or hall.

7.3. Room isolation (isovist area)

The relative isovist area (IA) is the average connectivity value of a convex space in a visibility graph which is normalised by being divided into the total number of grid squares (or total area of the house), as detailed in 4.4.2. This measure indicates the proportion of the direct visual information available to a space.

In general, the results in Section 5.4 suggested that the hall has the highest relative IA in the houses. It further suggests that a majority of Prairie houses (85%) feature a ranking sequence of *hall > dining room > living room > kitchen*. Considering the high occurrence of this sequence in Prairie houses, the focus of this section is only on the actual value of IA rather than the ordinal position of the spaces. The section analyses both factors of subtypes and service connections.

7.3.1. IA of rooms in subtypes

Isovist area is the direct visual connection or visibility, so the width of connections between spaces, especially relative to the size of the space itself, directly affects the relative IA. In addition, as it is the directly visible area from a space (the space itself excluded), the area of spaces adjacent to this space is another crucial factor. Therefore, it is possible to devise two hypotheses.

Hypothesis

Considering the subtypes, a factor is the position of the fireplace (side or centre), as this element is a major visual barrier inside the house, as previously explained in Section 7.2. Therefore:

a. Subtypes with the side fireplace (IA2 and IB2) might have the highest IA values in all public spaces, especially the living and dining rooms.
b. Subtype IB2 may also have a high IA for entry as it is bigger space adjacent to an unimpeded dining-hall-living room combination.

Results

Figure 7.8 illustrates the relative isovist area of the major spaces in the six subtypes. In this figure, each graph represents the IA of one major space among different subtypes.

The comparison of the IA of the spaces within the subtypes also shows a number of differences between them. As expected in hypothesis (a), the IA values of the dining and living rooms and hall are visibly higher in subtypes IA2 and IB2, which feature a side fireplace, than in IA1 and IB1 with a central fireplace. It reiterates the finding of the previous subsections that the position of the fireplace is crucial in the visual connectivity of the major public spaces, especially when compared to the position of the major spaces. Therefore, there is significant difference in the IA values of individual spaces across the subtypes which feature different positions for the fireplace. In regard to the difference between Victorian and Prairie houses, IB2 shows a departure from the former style in regard to the IA values of the living and dining rooms, while IA1 and IB1 show the most similarity to the average Victorian house.

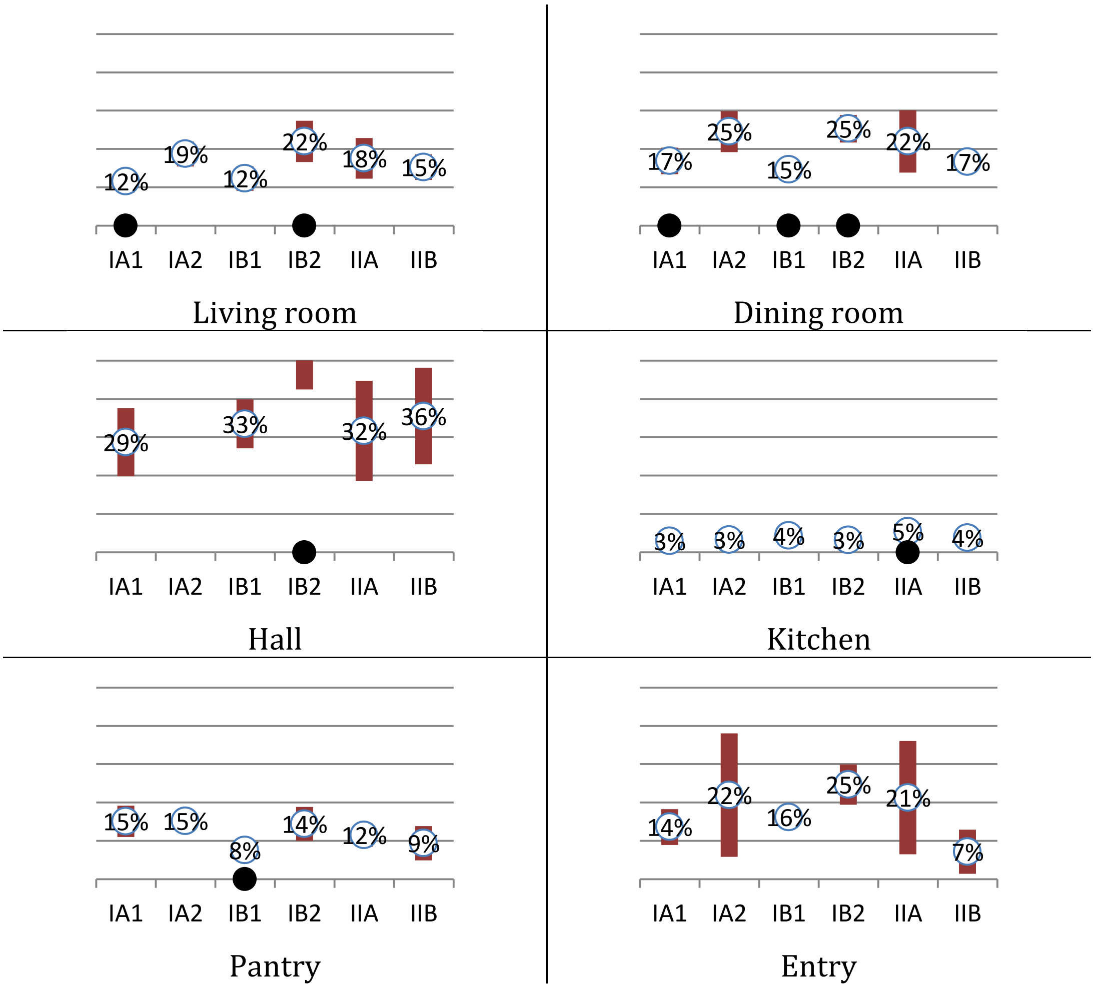


Figure 7.8. The average and standard deviation range of the relative isovist area (IA) of the major space in prairie houses based on subtypes.

7.3.2. IA of rooms regarding service connections

In Section 7.2, the data did not suggest an explanation for the service connections on the holistic isovist area of the house. Therefore, it is difficult to form a hypothesis for an effect on the rooms' IA values. Although the service connection increases the visual interaction between the connected space and service zone, the visual interaction is usually controlled by walls and different circulatory buffers, so that the undesirable direct visual contact (the matter of IA) may not occur. Hence, the results are compared without any specific hypothesis.

Results

Figure 7.9 shows the relative isovist area of the major spaces in regard to the connection of the service zone to the living room, entry, or hall.

The results suggest that there is generally no regularity between the service connections and the value of IA for the major spaces. The only exceptions are the lower IA values of the living room and entry when the hall-service connection is present. Similar to the holistic IA findings, this regularity is difficult to explain by consideration of just the service connections. However, one possible explanation is that the highest IA for living rooms belongs to IA2 and IB2, which feature a low number of hall-service connections. In contrast, IA1 has the highest number of hall-service connections (4 houses or 50%) while it also has the lowest IA for the living room (Figure 7.8). The combination of these two has may have affected the average values of IA in houses with and without the hall-service connections.

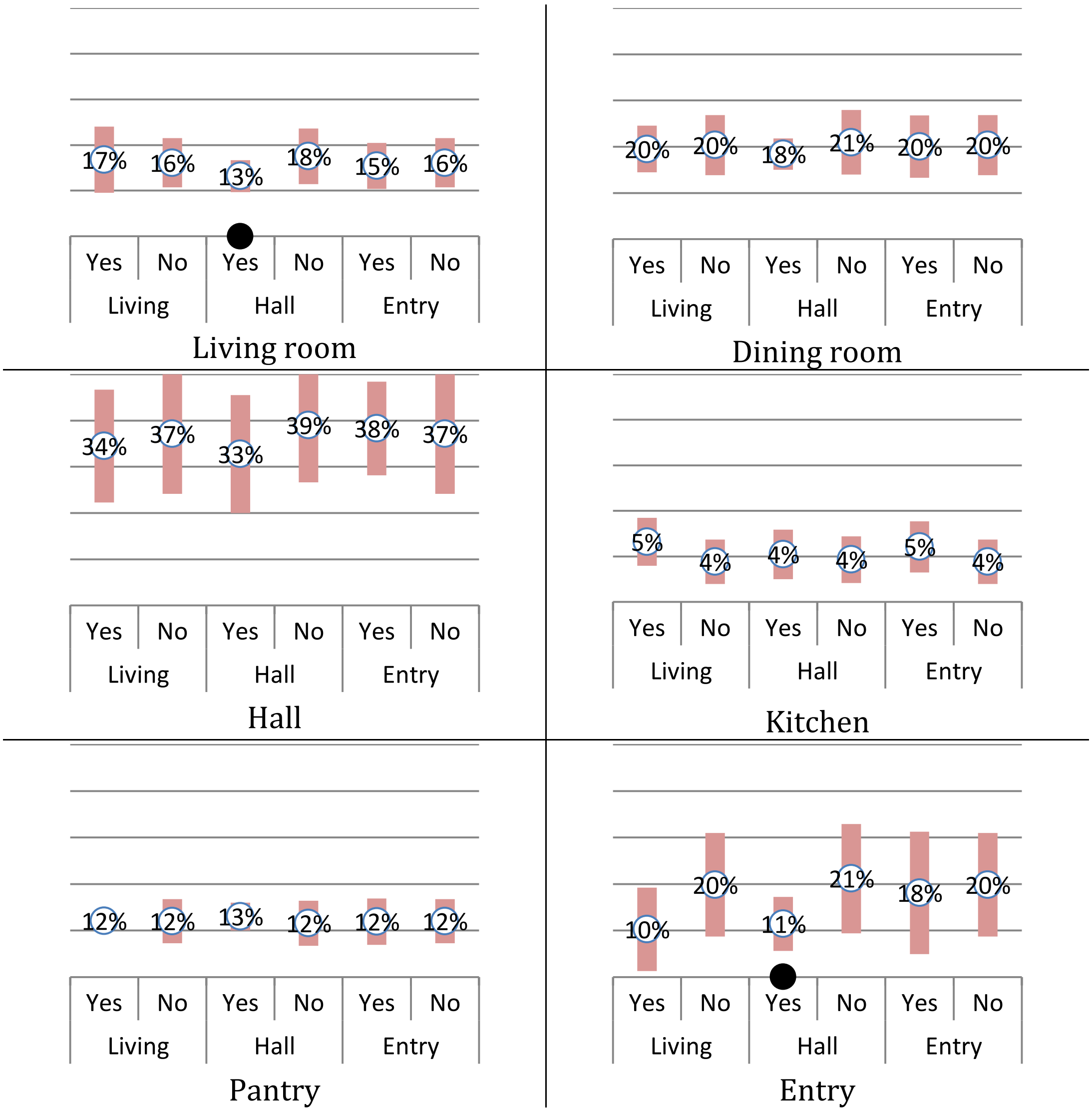


Figure 7.9. The average and standard deviation range of the relative isovist area (IA) of the major space in prairie houses based on service connections.

7.4. Room isolation (step depth)

The step mean depth (SMD) for a space reveals the number of straight paths necessary to go from an average point in that space to the rest of the house (see 3.3.3). This measure captures a degree of visual integration of a space in the whole house. In this section, the average SMD value of the major spaces are compared against the subtypes and service connections in Prairie houses in the two following subsections respectively.

7.4.1. SMD values and subtypes

The SMD values of the major spaces can be studied in two ways: their actual values, and their rankings.

Hypothesis

Considering the actual values of SMD, we would expect the same factors for the holistic measures (7.2), that is, mainly the position of the fireplace, to influence the results. Therefore, the hypothesis would be:

a. The SMD values of hall, dining room, and living room in subtypes IA2 and IB2 are lower because of their non-central fireplaces.
b. The entry's SMD value would be lower in IB2 because their entries have more opportunity to interact with the larger spaces of dining and living rooms.

Results

Figure 7.10 shows the actual SMD values for different spaces across the six subtypes. As can be seen, the significantly lower SMD of the living and dining rooms and the hall in IB2 meets the expectations in the first hypothesis (a). The living room also features a lower SMD but it is not significant. As expected from hypothesis (b), the entry of IB2 also has a lower SMD. On the other hand, the SMD values for all major spaces are the highest in IB1, although only two values (pantry and entry) show significance. There could be a two reasons for the lower visual connection in IB1. Firstly, it has a blocking fireplace in the centre of the house. Secondly, it has one of the lowest service connections- service connections theoretically decrease the visual distances between connected spaces.

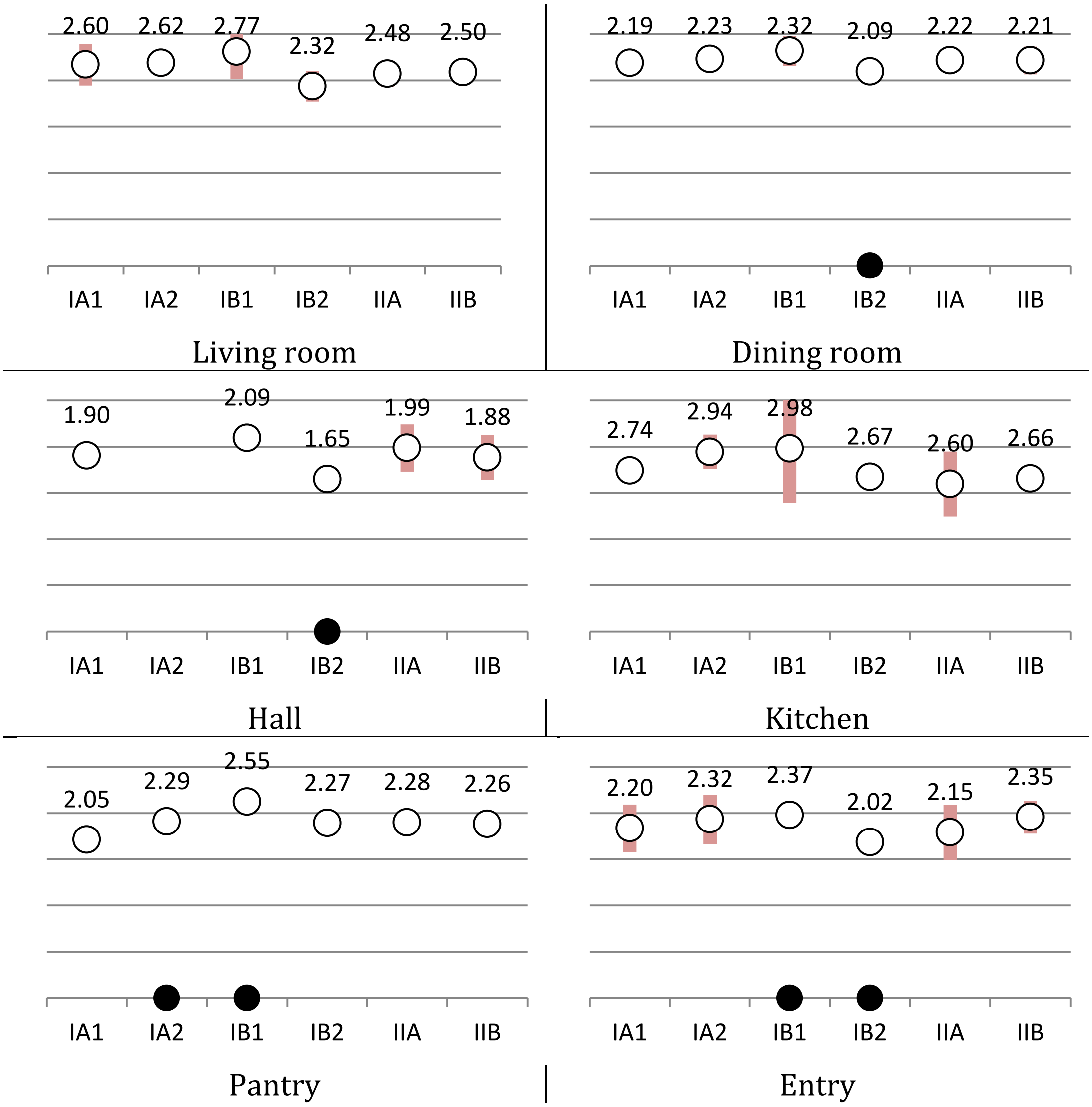


Figure 7.10. The average and standard deviation range of the step mean depth of major spaces in Prairie subtypes.

Figure 7.11 shows the ordinal scale of the spaces in the subtypes, arranged based on spaces (i.e. X-axis represent the subtypes). The results show differences in the living room, dining room, and pantry of subtype IIA. However, it is likely that the difference is more about the lack of a pattern in distribution of the values in this subtype. In subtype IB2, the data show more visual integration for the entry (in the sense that no entry belongs to the lower ranks).

Figure 7.11. The ordinal step mean depth of the major spaces in Prairie subtypes.

Figure 7.12 displays further details about the order of the SMD values regarding the common sequence of *(Hall) < dining room < living room < kitchen* (*H<D<L<K*) (see Section 5.4.2, Sequence 5.4). All houses in IB2 feature this sequence, making this subtype a representative of this sequence (although because p = 0.054, it was not rendered statistically significant).

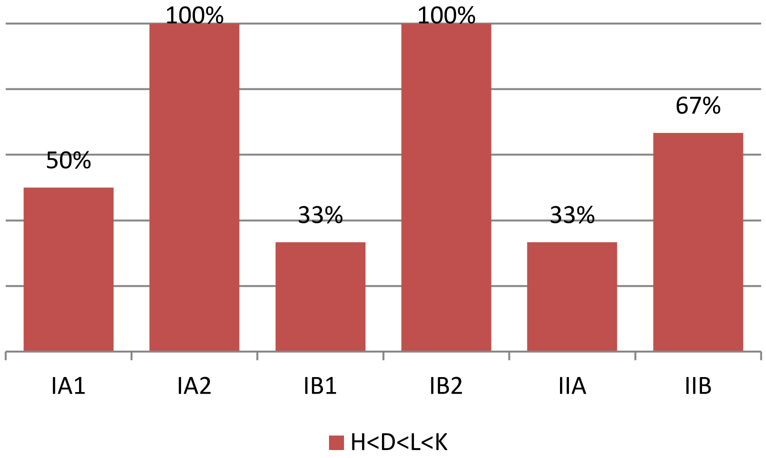


Figure 7.12. The occurrence of the sequence (H)<D<L<K among the subtypes.

7.4.2. SMD values and service connections

In this subsection, the values of step mean depth are compared against the service connections inside Prairie houses, seeking patterns in their presence or absence.

Hypothesis

A factor in the SMD value of a space would be a change in its visual connection to larger spaces such as the dining and living room. Otherwise, if the change is only related to such connections with smaller spaces (e.g., kitchen or entry), the difference may not be enough to form a significant pattern. In this regard, the connections to the service area are likely to affect mainly spaces in the service zone. Therefore:

a. In the existence of a service connection, the kitchen will have a lower SMD, which means it will be more integrated.

Results

Figures 7.13, to 7.15 show the actual SMD values for the major spaces in the six subtypes in regard to service connections. In these figures the black circle represents the significance ($p < 0.05$) of the observable difference in the SMD values of a space. The results support the hypothesis as the kitchen has a lower SMD when the service zone is connected to the entry or living room. There is also a difference in the pantry's SMD which cannot be explained by the connections. The pantry is usually on the other side of the service zone, close to the dining room. Therefore it is possible the visual connection between pantry and living room is mediated through the dining room rather any of the service-connections. In this regard, we cannot be as certain that the results are only related to connections.

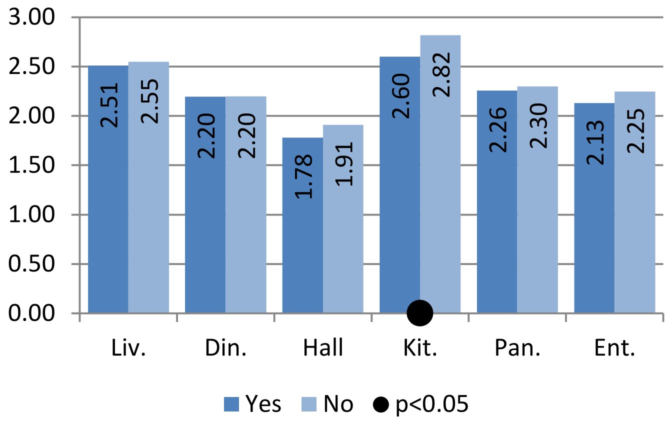


Figure 7.13. The step mean value for major spaces when the entry is ("yes") or is not ("no") connected to the service zone.

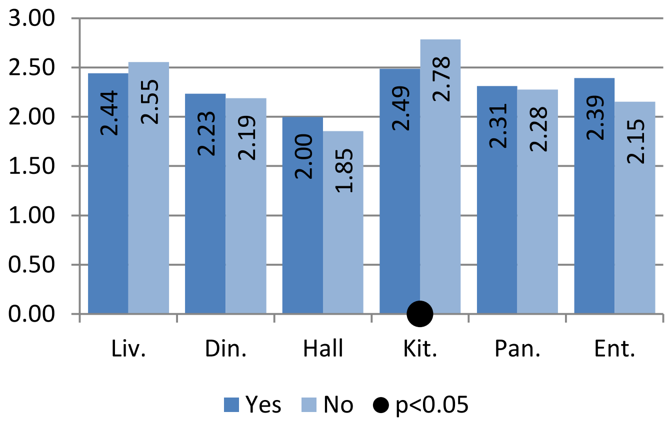


Figure 7.14. The step mean depth value for major spaces when the living room is ("yes") or is not ("no") connected to the service zone.

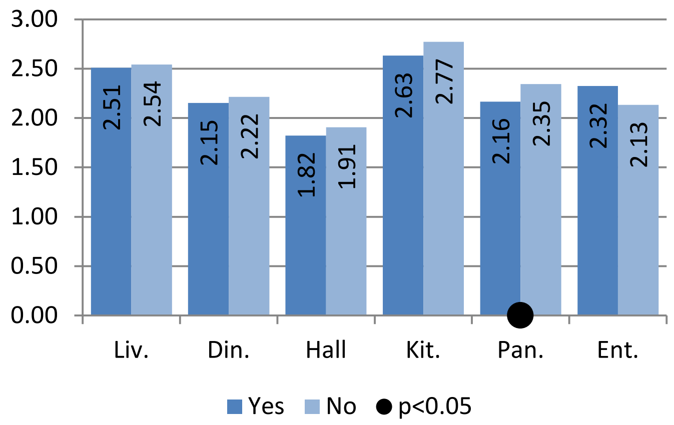


Figure 7.15. The step mean depth value for major spaces when the hall is ("yes") or is not ("no") connected to the service zone.

7.5. Room isolation (angular depth)

The angular mean depth (AMD) for a space reveals the number of turns (in degrees) necessary to go from an average point in that space to the rest of the house; however, the degrees are measured in the unit of turn (90°) (Turner, 2001a). The AMD is measured by averaging the angular mean depths of the spots in that space. Similar to SMD values, this measure captures a degree of visual integration of a space in the whole house (see 4.4.2). In this section, the AMD values are measured in the same manner as the SMD values in the previous section in both actual and ordinal values. Similar to the previous sections, the analysis is done for both subtypes and service connections.

7.5.1. AMD values and the subtypes

Angular mean depths generally follow the same principles of SMD values. Therefore, the same hypothesis and expectations of the previous section (7.4.1) are also valid for this section.

Hypothesis

Considering the actual values of AMD, the main factor is the position of the fireplace. Therefore, the hypothesis would be:

a. The AMD values of the hall, dining room, and living room in subtypes IA2 and IB2 are lower because of their non-central fireplaces.

b. The entry's AMD value would be lower in IB2 because their entries have more opportunity to interact with the larger spaces of dining and living rooms.

Results

Figure 7.16 shows the actual AMD values for different spaces across the six subtypes which are itemised on the X-axis. The results support the first hypothesis (a), as the IB2 houses with their side fireplace have more integrated living rooms, dining rooms, halls, and entries (i.e. their AMD is lower), although the results for living rooms are not significantly ($p < 0.05$) different from the other subtypes. The effect of fireplace position is more visible in the contrast between the AMD values of the dining room in IB1 and IB2.

In addition, the kitchens of IIA are significantly more visually integrated (AMD = 0.63) in the house than in other subtypes. This is reminiscent of the higher IA of these kitchens (see 7.3.1) and lower (though not significantly) SMD of IIA kitchens (see 7.4.1). Collectively, these three suggest that the kitchen in IIA is closer to the average Victorian kitchen than to the average Prairie kitchen.

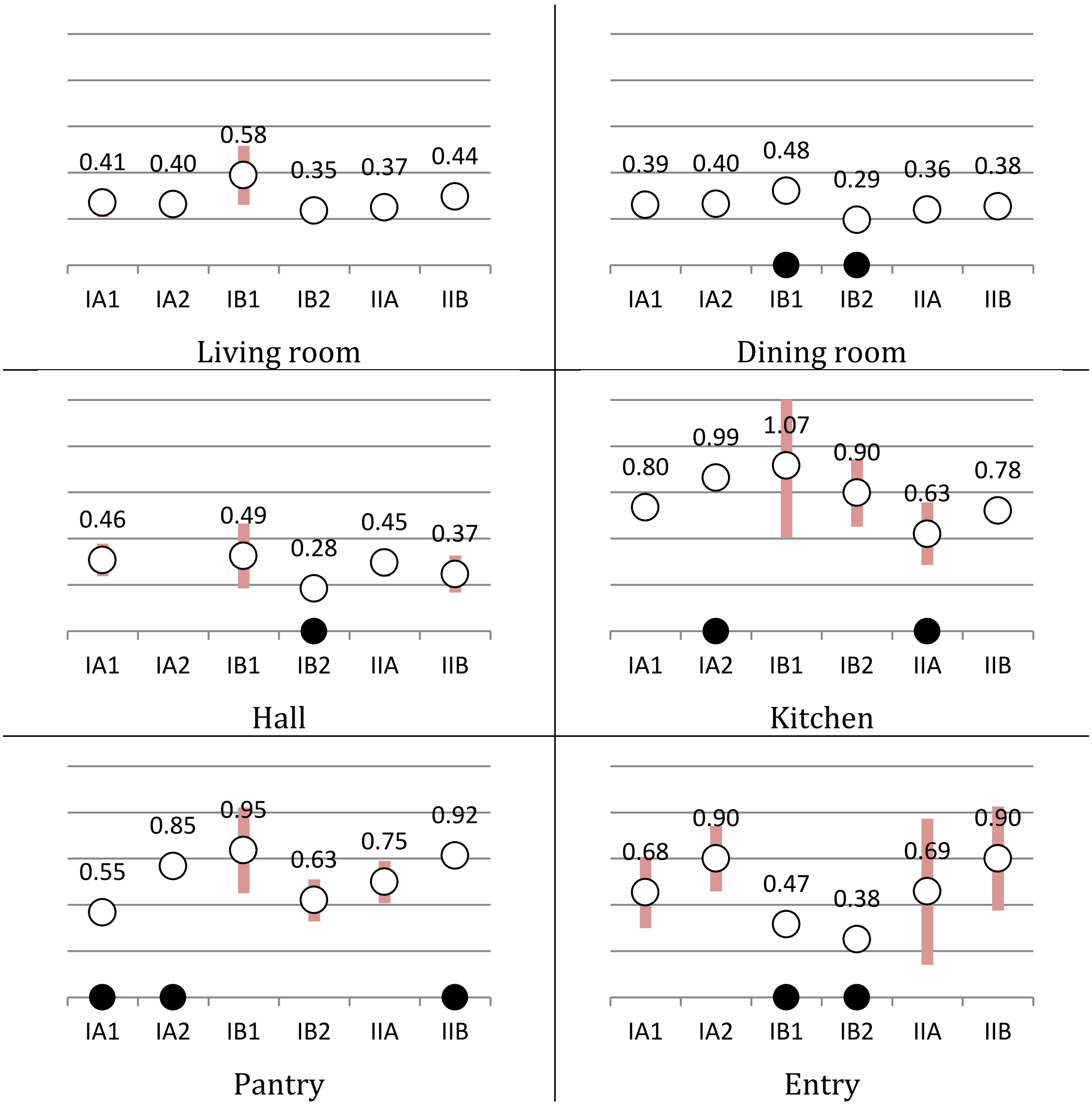


Figure 7.16. The average and standard deviation range of the angular mean depth of major spaces in the Prairie subtypes.

Figure 7.17 shows the ordinal scale of the spaces in the subtypes. Similar to the results for SMD (in 7.4.1), the AMD values of the living and dining rooms in IIA identify differences to the rest of the subtypes. For living rooms, it can be said that their ranking in IIA subtype is slightly higher (67% second-ranked) but for the dining room, the difference of IIA is more about the distribution of results between different ranks. Another similarity between these results and the SMD values in the previous section is the low rank of the kitchen in IB2 (though in the previous section, this item was not statistically significant).

Figure 7.17. The ordinal angular mean depth of the major spaces in Prairie subtypes.

Although the overall rankings of the spaces are roughly similar between the SMD and AMD results, the occurrence of the sequence of *(Hall) > Dining room > Living room > Kitchen* varies between the two measures. Figure 7.18 shows the occurrence of this sequence for the AMD results in the six subtypes (cf. Figure 7.12, in Section 7.4.1). The above sequence is not as strong in IB2 (20%) as it was for the SMD values (100%).

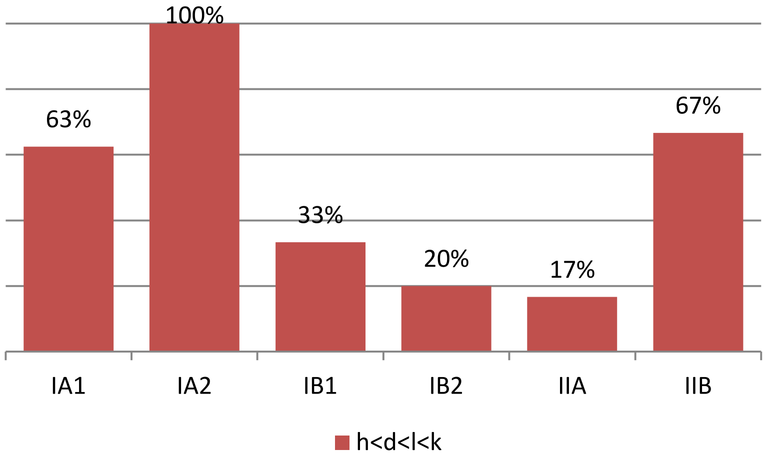


Figure 7.18. The occurrence of the sequence (H)>D>L>K in the Prairie subtypes.

Overall, the data suggests that the subtypes of Prairie houses have a relative effect on the angular depth of the major spaces. In contrast to the SMD results, this effect is more visible in the order of the AMD values than in their actual values.

7.5.2. AMD values and service connections

In this subsection, the values of angular mean depth are compared against the existence of the service connections in Prairie houses. In many ways, the service connections affect the angular depths in a similar manner to the step depths discussed in 7.4.2. Therefore, the hypothesis also remains the same:

a. In the presence of a service connection, the kitchen will have a lower AMD, which means it will be more integrated.

Results

Figures 7.19 to 7.21 show the AMD values for the major spaces in the six subtypes, based on a service connection. The results are similar to those of SMD, supporting the hypothesis that the kitchen has a lower AMD when the service zone is connected to the entry or living room. There is no meaningful difference for the AMD of connected spaces for the hall-service connection.

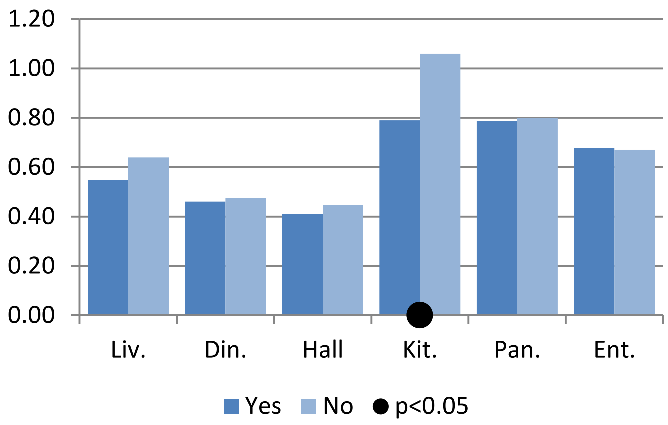


Figure 7.19. The angular mean value for major spaces when the entry is ("yes") or is not ("no") connected to the service zone.

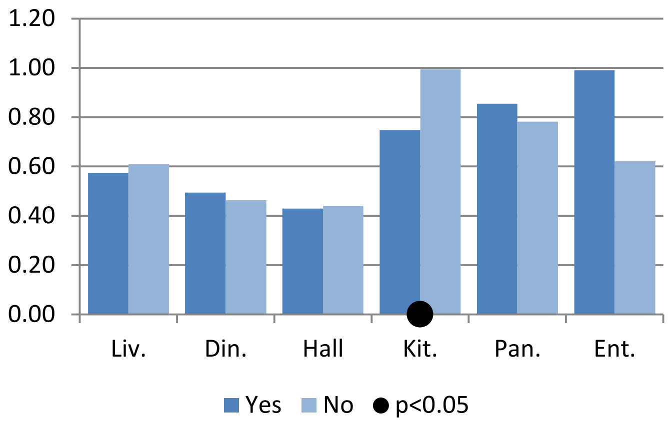


Figure 7.20. The angular mean value for major spaces when the living room is ("yes") or is not ("no") connected to the service zone.

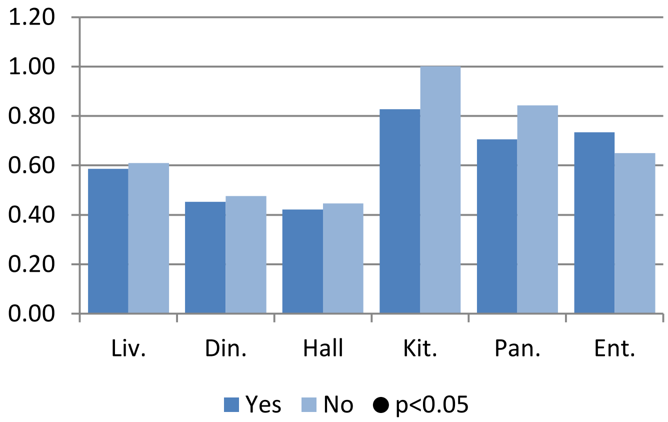


Figure 7.21. The angular mean value for major spaces when the hall is ("yes") or is not ("no") connected to the service zone.

7.6. Interspatial depth (step)

The step interspatial depth (SID) between two spaces is the average number of straight lines that a person needs to take in order to go from any point on one space to any point in the other (the minimum number is 1) (see 4.4.5). The lower interspatial depth between two spaces indicates a higher visual connection between them. In this section, the SID values between the four "squares" of the houses (living and dining rooms, kitchen, and entry) are measured and analysed. The kitchen represents the service area; living room stands for public and social life; dining room is the buffer zone between the service and public area; and the entry is where a visitor is introduced to the house. Therefore, there are six measure variables including the SID between living room and kitchen (L-K), living and dining rooms (L-D), dining room and kitchen (D-K), entry and kitchen (E-K), entry and living room (E-L) and entry and dining room (E-D). This analysis is performed for two factors of subtypes and service connections (discussed in respective subsections).

7.6.1. SID and Prairie subtypes

In general, the interspatial depths depend on the width of the openings between spaces and the hindering elements, as well as the size and position of the spaces. Hence, it is possible to devise the hypotheses as follows.

Hypothesis

Regarding the elements blocking the visual connections, the fireplace appears to be the most influential factor (as suggested in the previous sections: 7.2.1 to 7.5.1). In addition, it is suggested that the service connections may also reduce the depth between kitchen and living room (this assumption is thoroughly discussed in the next subsection). Based on these two suggestions, the hypotheses are:

a. The E-K and L-K depths will be lower in type II because they have more service connections.
b. Houses without a central fireplace (IA2 and IB2) have a lower L-D SID than houses with a central fireplace (IA1 and IB1).

c. Houses of IA1 and IA2 with entry and service areas on the same side will have lower SID values for both E-K and L-K than houses with the entry in the opposing wings of the service area (subtypes IB1 and IB2). This is because the entry provides a shortcut between the living area and service zone.

Results

Figures 7.22 shows the average SID values of the two types (I and II) to examine the first hypothesis (a). In this figure the bars represent the average SID values while the diamond markers indicate the standard deviations. This data does not support the hypothesis (a) as there is no significant difference found between the types.

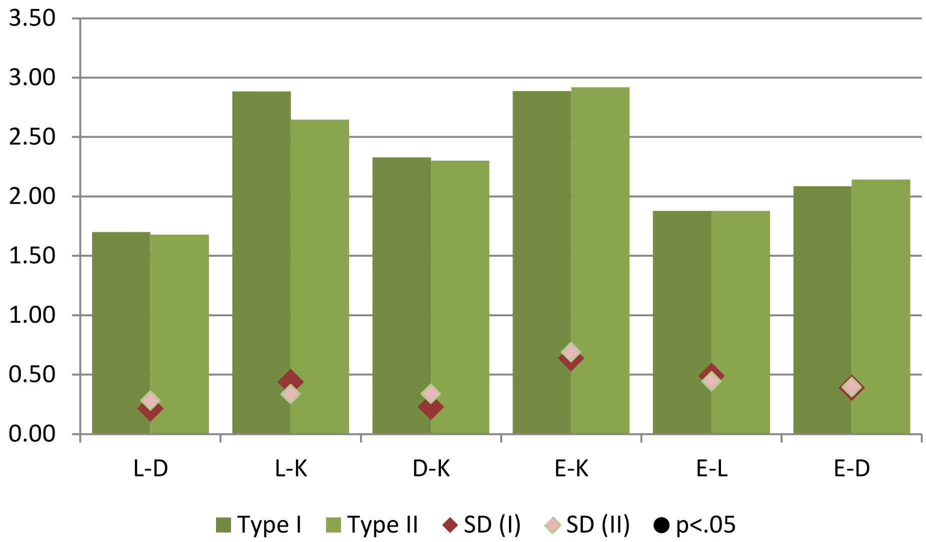


Figure 7.22. The step interspatial depths between the four squares in types I and II.

Figure 7.23 shows the average SID values for the subtypes. The numbers are shown as the average (white circles) and the normal distribution range (red bars). The black circles on the X-axis in Figure 7.8 show that the differences are also statistically valid (significance $p < 0.05$).

As expected in hypothesis (b), the living and dining rooms are syntactically more connected in houses with a side fireplace (1.61 in IA2, and 1.52 in IB2) than in houses with central fireplace (1.75 in IA1, and 2.00 in IB2). These spaces are closer to each other in subtype IIA (SID = 1.55) as they are directly connected to each other, while there is the hall-entry space mediating between them in subtype IIB (SID = 1.94).

Contrary to hypothesis (c), the average depth between the living room and the kitchen does not differ significantly (under 5%) for all subtypes except IB1 (d = 3.27). However, considering the high SD in this subtype and the low number of houses (3), no conclusion is drawn about the relationship between subtypes and the value of L-K SID.

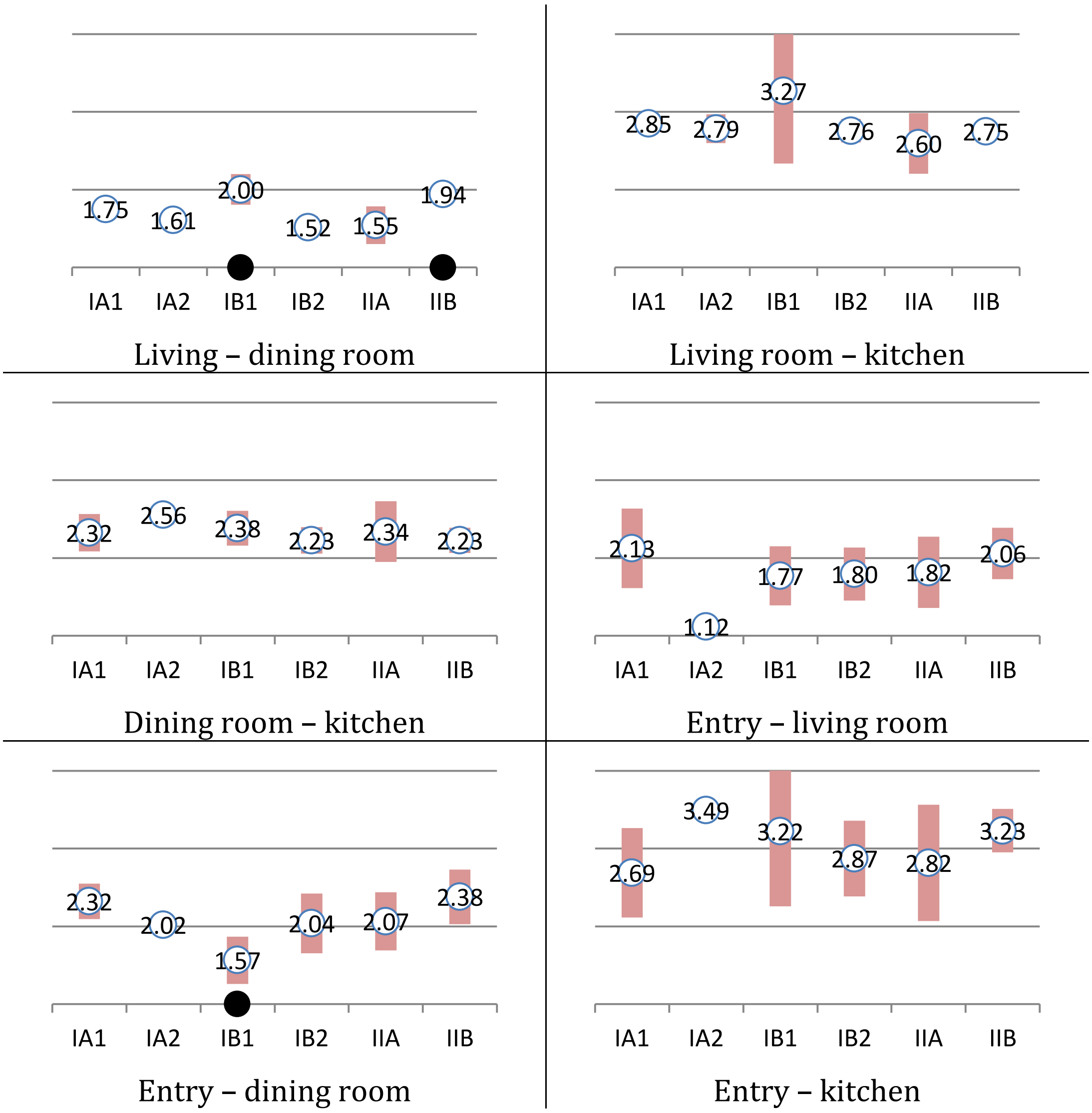


Figure 7.23. The average and standard deviation range of the step interspatial depth between the specified spaces.

Figure 7.24 shows the ordinal ranking of the SID values (the higher rank means a lower SID or more visual connection). The data show a number of significant differences between subtypes. An interesting difference is that the rank of E-D depth in IB1 is higher while the rank of E-L depth in this subtype is slightly lower than in other subtypes. In Section 5.7 (Sequence 5.12), the sequence *E-D < E-L* was suggested to be a feature of Victorian houses. The other significant difference is in the D-K, E-L, and L-K depths of the subtype IIA, although this difference appears to be more related to the erratic distribution of the values rather than a regular feature of the subtype IIA.

Figure 7.24. The percentage of houses in subtypes based on the ordinal scale of step interspatial depth between the specified spaces.

Figure 7.25 shows the occurrence of the most common sequences of SID orders in the Prairie houses, in regard to the subtypes (see 5.7 for these sequences). While in no cases $p < 0.05$, the presence of these sequences is very low in IB1.

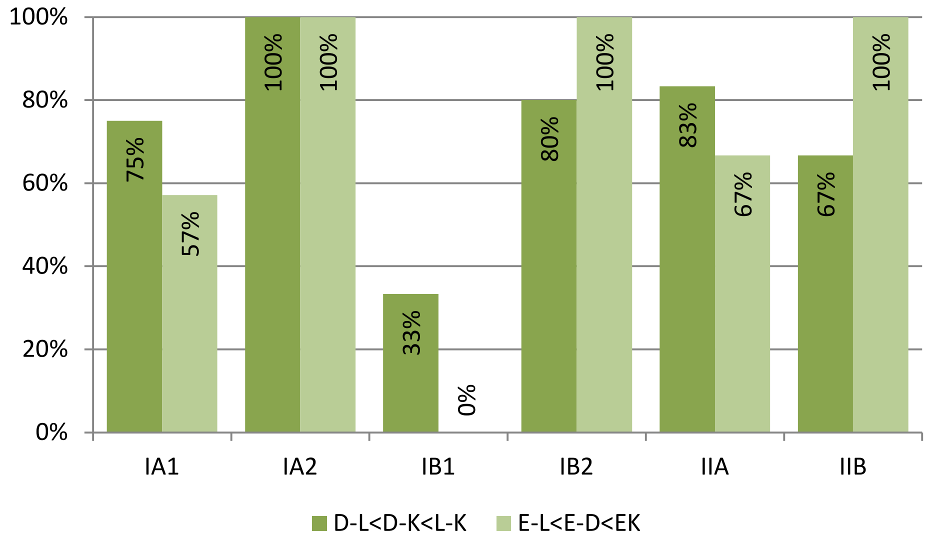


Figure 7.25, the occurrence of the common SID sequences in the six subtypes.

7.6.2. SID and the service connections

The results in the previous sections suggested the possibility that the existence of service connections reduces the visual depth between the kitchen and the connected space. In this subsection this possibility is analysed.

Hypothesis

a. A lower SID is expected for L-K and E-K when the respective connections are present.
b. Considering the dining room is always connected to the service zone, the ranking of SID for D-K will be lower that L-K and E-K in houses without the respective service connections.

Results

Figures 7.26 to 7.28 shows the SID values for houses with and without certain connections to the service area. In this figure, the horizontal marker lines represent the average values for *all* houses while the bars stand for the average SID values in respective houses with ("yes") and without ("no") the specified service connections.

As expected from hypothesis (a), the existence of the living-service connection reduces the visual depth between the living room and kitchen. Similarly, the entry-service connection visibly reduces both E-K and L-K depths; however, the significance of this reduction is not supported by *p*-value, although it is also not too high (0.056 and 0.067, respectively).

There are differences in D-K, E-L, and E-D based on the hall-service connection. When this connection is present, the E-L and E-D become substantially more distant (higher SID). The reason for this is unknown to the author, but a plausible conjecture could be that a hall-service connection makes the hall "dirtier" and less favourable, and so requiring more distance from the living room. Considering that the hall usually mediates between the entry and living room, its higher distance from the living room automatically means more distance between living room and entry.

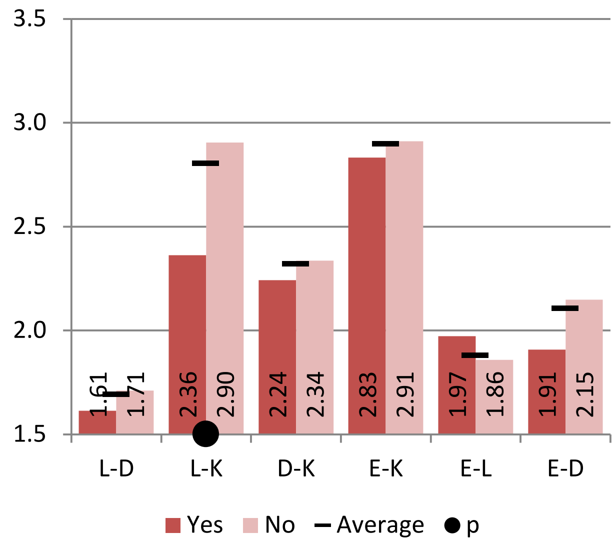


Figure 7.26. The average interspatial step depth values for houses with or without living-service connections.

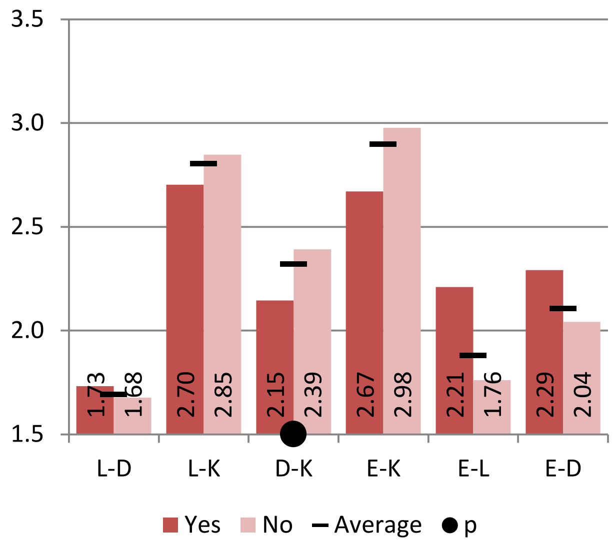


Figure 7.27. The average interspatial step depth values for houses with or without hall-service connections.

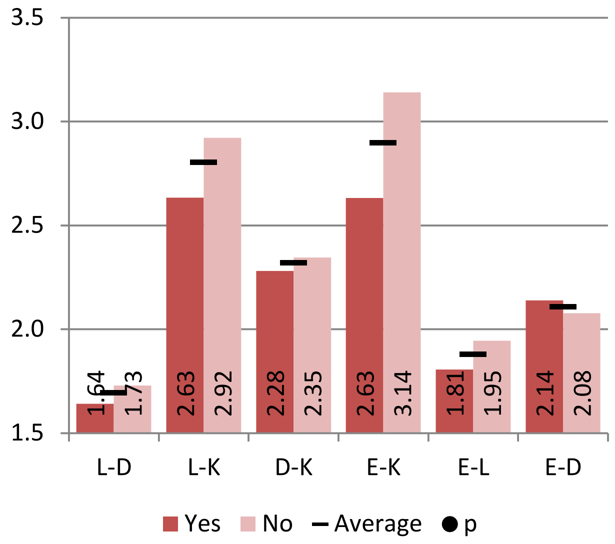


Figure 7.28. The average interspatial step depth values for houses with or without entry-service connections.

7.7. Interspatial depth (angular)

The angular interspatial depth (AID) between two spaces is the average amount of turns (in angle) that a person needs to take to go from any point on one space any point in another (the minimum number is 0) (see 4.4.5). Based on Turner's notion (2001a), a 90-degree turn is considered a full turn that is represented by a depth value of 1.00. A lower AID between two spaces indicates a higher visual connection between them. AID values will be similar to SID values, except that for AID the *amount* of turns is important rather than the number of turns.

Similar to the previous section, the AID values between the four "squares" of the house (kitchen, living and dining rooms, and entry) are measured, amounting to a total of six measures of AID between living room and kitchen (L-K), living and dining rooms (L-D), dining room and kitchen (D-K), entry and kitchen (E-K), entry and living room (E-L), and entry and dining room (E-D). Similarly, two sets of factors are investigated – the subtypes that are the positioning of the spaces and elements, and the connections of the service area with other spaces. Considering that the bases of SID and AID are similar, the same hypothesis are also considered for this section (even those rejected in the previous section). The following subsections analyse the AID values in the subtypes and service connections, respectively.

7.7.1. AID and the Prairie subtypes

Hypothesis

a. The E-K and L-K depths will be lower in type II because of more service connections.
b. Houses without a central fireplace (IA2 and IB2) have a lower L-D AID than houses with one (IA1 and IB1).
c. Houses of subtypes IA1 and IA2 with entry and service areas on the same side will have both lower E-K and L-K AID values than houses with an entry in the opposing wings of the service area (subtypes IB1 and IB2). This is because the entry would provide a shortcut between living and service zones.

Results

Figure 7.29 shows the average AID values of the two types (I and II). In this figure the bars represent the average SID values while the diamond markers indicate the standard deviations. The results show significant differences in the L-K and D-K results of the two types. Depths are lower in Type II, partially supporting hypothesis (a). These results are generally distinct from those of SID (Figure 7.22).

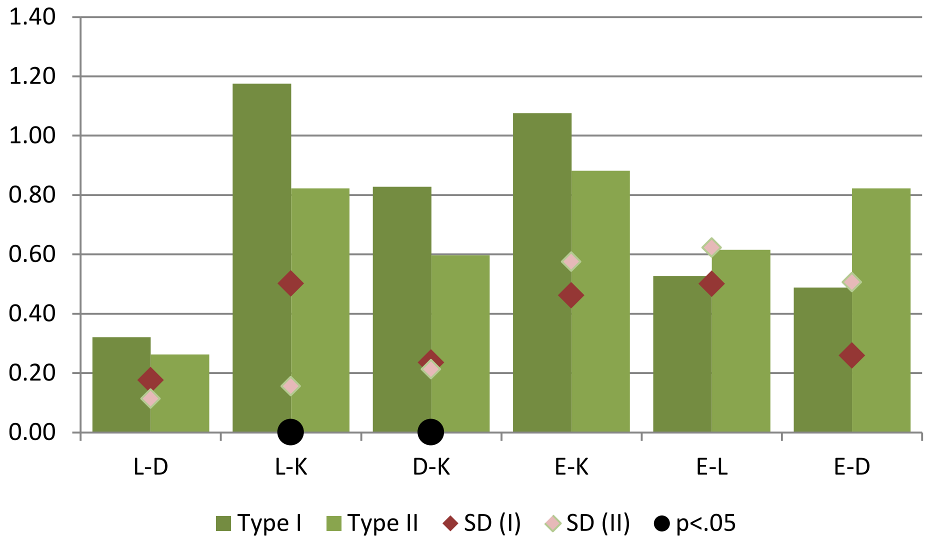


Figure 7.29. The angular interspatial depths between the four squares in types I and II.

Figure 7.30 shows the actual AID values between major spaces across the six subtypes. In this figure, each graph shows the AID values for one measured spatial depth in the six subtypes. In these graphs, the white circle represents the average AMD values and the pale red bar indicates the standard range of deviation.

As expected in hypothesis (b), the L-D depth in houses with a central fireplace (0.41 and 0.49) is higher that the values for houses without it (0.28 and 0.15). Significant differences are also observed in the E-D of IIB subtype and D-K of IA1 and IA2. The latter has a contrast to the SID of D-K for the same type.

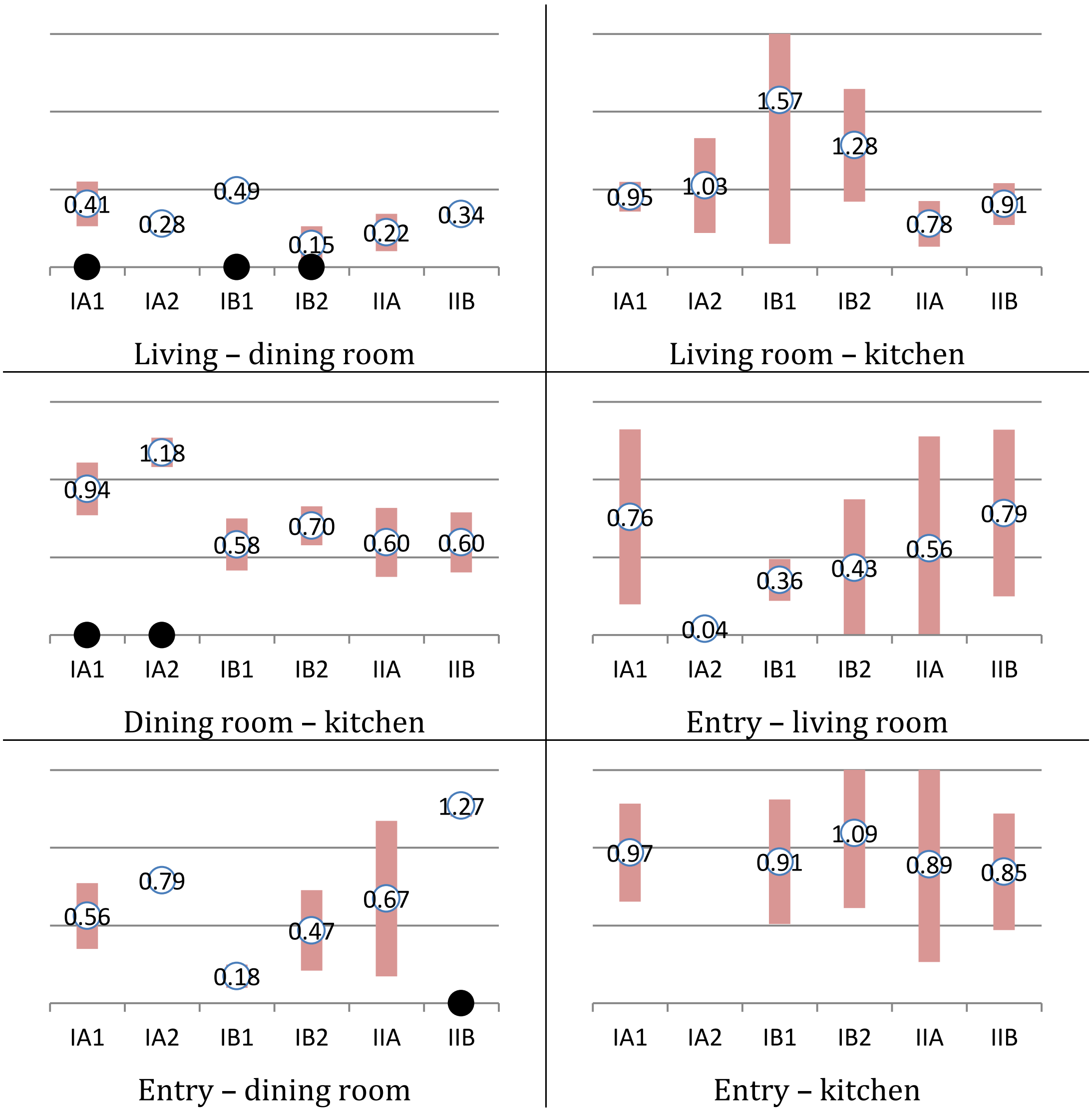


Figure 7.30. The average and standard deviation range of the interspatial angular depth between the specified spaces, arranged based on spaces.

Figure 7.31 shows the ordinal ranking of the AID values (a higher rank means lower AID, or more visual connection). The results mirror the findings of the previous section (Figure 7.24) about the higher E-D rank and slightly lower E-L rank in IB1. Furthermore, subtype IB1 differs from other subtypes by having a lower ranked L-D (66% middle and last). Another major pattern of difference pertains to IA1, with more visual interaction of entry with living and dining rooms (E-L and E-D). However the ranks of D-K depth in this subtype are lower.

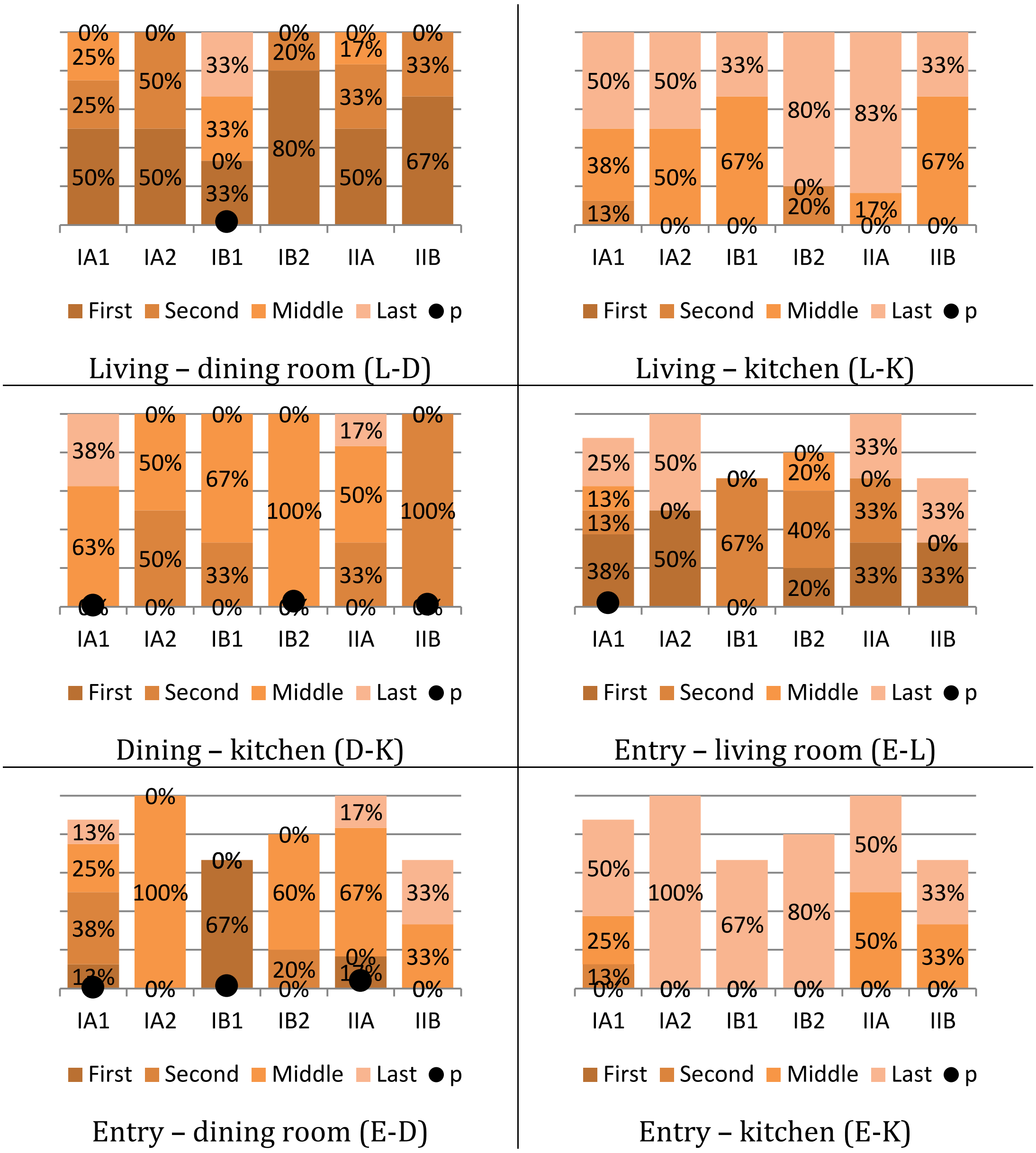


Figure 7.31. The percentage of houses in subtypes based on the ordinal scale of interspatial angular depth between the specified spaces.

7.7.2. AID and service connections

The AID measure has a similar foundation with SID, and thus the expectation for interspatial depth would not be much different from that of the SID measure. Therefore, the following hypothesis is similar to the hypothesis provided in 7.6.2.

Hypothesis

a. A lower AID is expected for L-K and E-K when the respective connections are present.
b. Considering that the dining room is always connected to the service zone, the ranking of AID for D-K will be lower than L-K and E-K in houses without the respective service connections.

Results

Figures 7.32 to 7.34 show the SID values for houses with and without certain connections to the service area. In this figure, the horizontal markers represent the average values for all houses while the bar charts stand for respective houses with ("yes"), and without ("no"), the specified service connections.

The results mirror those for SID values in Figures 7.26 to 7.28 (see Section 7.6.2). However, the effect of living-service connection of L-K and E-K depths seems to be lower for angular results than for step depth results, as it is not validated by the *p*-value significance. The effect of hall-service connection on the angular depth of the E-L and E-D connections is also lower than on the step depth although it is still visible.

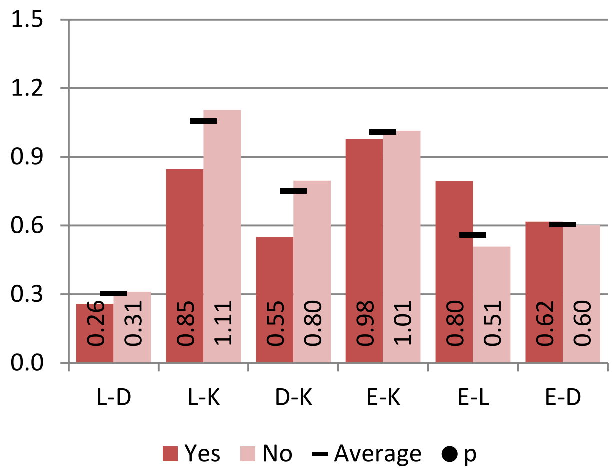


Figure 7.32. The average interspatial angular depth values for houses with or without living-service connections.

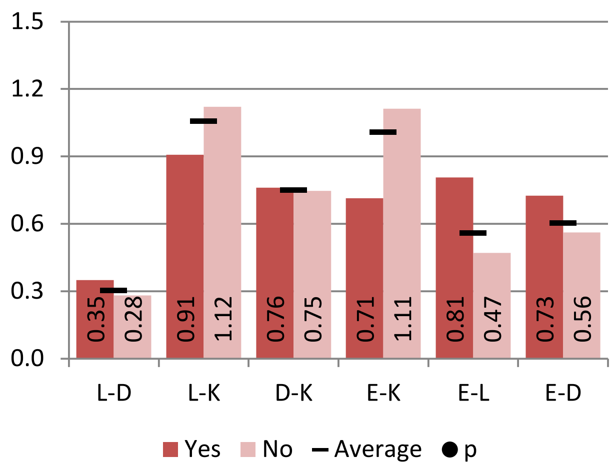


Figure 7.33. The average interspatial angular depth values for houses with or without hall-service connections.

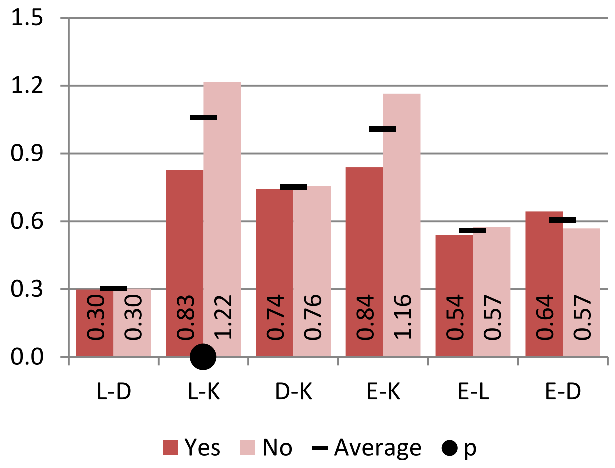


Figure 7.34. The average interspatial angular depth values for houses with or without entry-service connections.

7.8. Visual significance of the fireplace

Hypothesis

As explained in Chapter 2, the fireplace is considered a focal element in the Prairie house, with an implication of its visual centrality. However, considering that the position of fireplace affects visual features of Prairie houses, it is presumable that the same factor affects the visual significance of the fireplace. Hence, we can hypothesise:

a. The subtypes IA1 and IB1, with their central fireplaces, will also have more visually significant fireplaces.

Results

Figure 7.35 shows the average angular and step depths for the fireplace among the six subtypes. The average and standard deviation range are shown by the white circles (and representing number) and the bar chart, respectively.

Both depths show a similar order of subtypes, from lower to higher, IA1, IA2, IIA, IB2, IB1, and IIB. As expected, IA1 had the lowest fireplace depths (SMD of 1.38, AMD of 0.17), however it is matched with IA2 not IB1, contrary to the expectation. Meanwhile, the visual depth of the fireplace in IB1 is more similar to that of IB2. This suggests that the typological features (the position of the entry) may be comparably important. This can be related to the fact that the fireplace is mainly located in the living room, and so the lower depth to the living room may stand for the lower depth to the fireplace as well. A support for this assumption comes from the interspatial depths between the living room and kitchen (L-K) in these subtypes (Figures 7.23 and 7.30) also being lower. The lower L-K occurred more when the entry was connected to the kitchen (Figures 7.28 and 7.34). The main difference between the subtypes IA (IA1 and IA2) and IB (IB1 and IB2) is that the former features more entry-service connections.

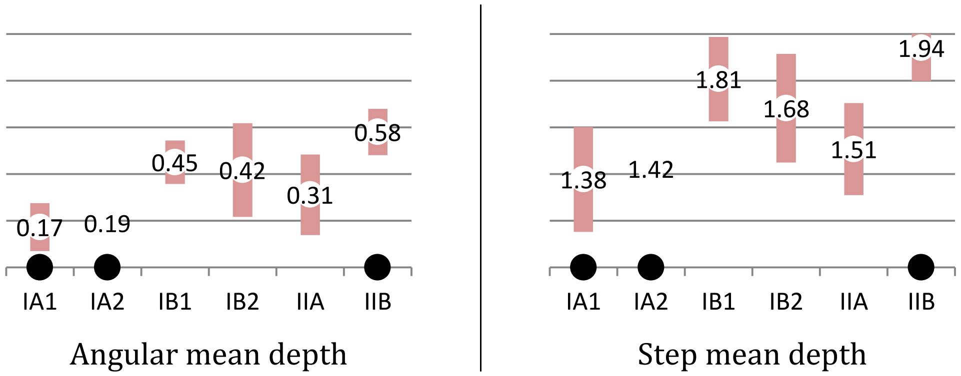


Figure 7.35. The average AMD and SMD of the fireplace in the Prairie subtypes.

Figure 7.36 shows the significance of the fireplace in the houses of each subtype compared to the spots with minimum AMD. The percentages signify the depth of the fireplace (see 4.4.6) relative to both the most integrated points (minimum AMD) and an average point in the house. The subtypes differ significantly in the visual significance of the fireplace. Subtype IA1 has the most focal fireplace (2% less deep than the minimum AMD). The second most visually important fireplace belongs to subtype IA2 (17%). The visual significance of the fireplace decreases in subtype IB2 (82%). In IIB the fireplace is just another average position in the house (101%) however, due to its small data set this is difficult to validate.

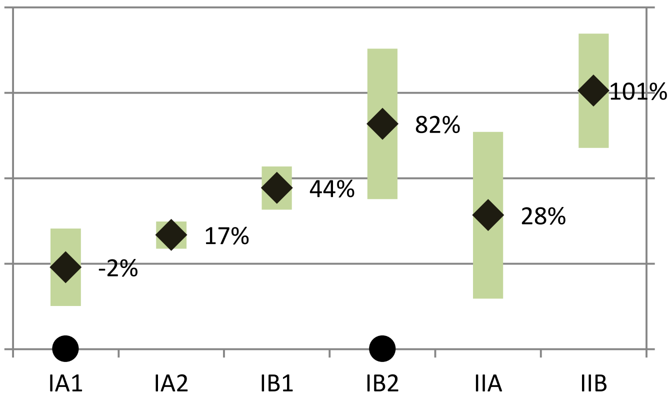


Figure 7.36. The visual significance of the fireplace (D) in the Prairie subtypes. The lower numbers indicate a higher significance.*

Overall, the visual significance of the fireplace is seemingly affected by its position relative to the dining and living rooms. In houses with the fireplace hindering the view between these spaces (as in IA1 and IA2), the fireplace becomes more visually integrated than the rest of the house which can be interpreted as a special feature of this element. However, the fireplace becomes less visually integrated in the house when the fireplace is not placed between the living and dining rooms, especially when it is located on a side of the living room (as in IB2). Therefore, the fireplace is not often in the visual centre of the house, in contrast to the suggestions in the literature.

7.9. Summary

In this chapter, eight measures of isovist mapping or visibility graph analysis (VGA) were applied to Prairie houses. The results showed that the position of the fireplace was the main factor differentiating between the various subtypes. The service connections were another factor which seemingly affected some of the results. In contrast, the layouts (types and subtypes) had less effect on the results for some spaces. Unlike the results of the convex mapping analysis in the previous chapter, these factors had generally less degree of certainty. At best, they can be considered as providing more opportunity for certain topological features. Below is the summary of the results:

The majority of significant differences between the subtypes were related to the positioning of the fireplace in Type I. The differences include:

- Subtype IB2 (with its non-central fireplace) had the highest average isovist area with lowest average angular and step mean depths, making it the most holistically perceived subtype (if holism is interpreted as visual connection).
- Generally, the social spaces (hall, living, and dining rooms) of IB2 have the highest visual connections (IA, AMD, and SMD) while they have the lowest visual integration in IA1 and IB1 (with central fireplace).
- The living-dining room (L-D) visual interspatial depth is the lowest for IB2 and highest in IA1 and IB1.
- On the other hand, the fireplace itself is more visually emphasised in IA1, and less so in IB2.

While the fireplace was the most important factor in visual terms, other typological factors also appeared influential:

- Type II has on average a higher visual connection (lower SID) between the kitchen and living room (L-K).
- The kitchen in IIA has a lower AMD.
- The subtype IB1 has higher visual connection between entry and dining room.

Another factor is the service connections in the house. In general, these connections exert more influence on the interspatial depths, although a few other measures were also influenced by them:

- In the presence of an entry-service connection, the holistic angular mean depth is reduced (i.e. higher integration).
- The hall-service connection is associated with lower visual interaction for entry: lower isovist area, higher SID for E-L and E-D, and higher AID for E-L.
- The presence of entry-service connection reduces several depth measures related to the kitchen, including the kitchen's AMD and SMD, L-K in AID and SID, and E-K in SID.

A direct relationship between the layout factors and results were often easily inferred, especially in the case of fireplace and entry-service connections. However, for a few factors such as hall-service connections, such relationships were harder to establish. It is assumed that there are other layout factors which are also pertinent when a hall-service connection is present.

Regarding the comparison between Victorian and Prairie houses, subtype IB2 shows the highest visual connections holistically and between the social space, which make it the most different to the former style. On the other hand, subtype IB1 and IA1 has the lowest of such visual connections, but the highest visual focus on the fireplace. IB1 also resembles Victorian houses by featuring a lower entry-dining room (E-D) depth. Subtype IIA has slightly more integrated kitchens which is arguably a Victorian feature.

8. Axial mapping measures

8.1. Introduction

In the previous two chapters (6 and 7), the topological features of Prairie houses have been analysed using convex and isovist mappings. In this chapter, the same houses are analysed using axial mapping. Axial mapping is used to study movement, visual axes, and decision-making inside a space (see 3.3.2).

In this chapter, the axial measures are derived using the same set of layout features of Prairie houses, including comparison against Pinnell's types (see 2.4.1), and consideration of service connections, (see 4.3.3). This chapter has four sections (excluding this introduction). The first section presents the results of the location of the highly integrated axial lines (HIALs). The second section discusses the spaces crossed by the HIALs. Section 8.4 investigates visually important intersections inside the houses, and, finally, section 8.5 summarises the findings of this chapter.

8.2. Major axial lines

The axial lines with higher integration values are more likely to be passed and are more decisive in the movements in the space (see 3.3.2). In this section, the highly integrated axial lines (HIAL) are investigated. To limit the axial lines to a comparable set, three major axial lines were considered which pass between the ever-present "squares" (living room, dining room, and kitchen/service zone) in the houses. The percentage of houses with an HIAL between these spaces were recorded. This section is divided into two subsections. In the first subsection, the correlation between the subtypes and the axial lines is analysed. In the second subsection, the HIALs are compared against the presence of service connections.

8.2.1. Subtypes and HIALs

This subsection analyses the position of the HIALs among the subtypes of Prairie houses. Considering the very high axial intelligibility of Prairie houses (see 5.3), we expect that there is a strong correlation between the connectivity and integration values. Therefore, the hypothesis is devised based on this premise.

Hypothesis

The axial lines that are likelier to be crossed by more axial lines are those with highest integration as well. Therefore, we base our hypotheses on which lines are more likely to be crossed in the houses:

a. The axial line between the dining and living rooms (DxL) would be crossed by more HIALs, because such a line is almost always present in the houses and it is relatively long, making it more likely to be connected to other axial lines. So, no particular difference between subtypes is expected.
b. The axial line between the service zone and living room (SxL) is the least likely to be an HIAL, mainly because it is not a common line (as service zone and living room are rarely connected). However, considering that the living room and service zone are opposite each other in type II, it is expected that the subtypes of this type (IIA and IIB) will have more SxL as HIALs.
c. The axial line between the kitchen and dining room (DxK) is more likely to be an HIAL than SxL because it often exists. However it is not as prominent as DxL because it is shorter and so has less chance of crossing other lines.

Results

Figure 8.1 shows highly integrated axial lines (HIAL) among the six subtypes. The results support the first expectation (a) as there is no significant difference found in the subtypes, although a dining-living room axial line (DxL) is present more in IB2 (80%), and less in IA1 (25%).

There are generally less HIALs between the service area and living room (SxL) in all subtypes except IB1 and IIB. Nevertheless the hypothesis (b) is relatively supported as subtypes of type II have more SxL HIALs.

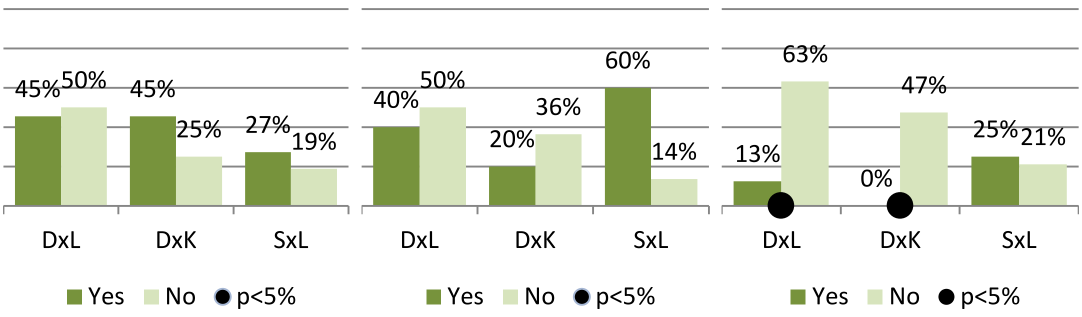
The third hypothesis (c) is also supported by the data as no significant difference is measured in the results for the DxK HIAL, although it is less present in IA1 (13%) and IB2 (0%).

Figure 8.1. The percentage of houses in subtypes in which certain HIALs are present.

8.2.2. Service connections and HIALs

The results are also investigated for the connection of the service area to the other "squares" of the house (excluding the dining room, which is always connected to the service area). Figure 8.2 shows the difference between the existence of HIALs in situations whether the service area is ("yes"), or is not ("no"), connected to the other squares.

The likelihood of an HIAL passing the living room increases when there is a connection between the service zone and living room or entry, however the significance of this difference is not statistically supported. On the other hand, this connection does not have any correlation with the DxK axial line. The connection between the hall and service area significantly decreases the chance of an HIAL between the dining room and the two spaces of living room (DxL) and kitchen (DxK). This may be because such a connection may provide more opportunity for other axial lines passing through hall to be an HIAL. In any case, the connection of the service zone to other rooms seems to play a partial role in defining the HIALs.



Entry – service | Living room – service | Hall – service

Figure 8.2. The percentage of houses with a certain HIAL passing through them when a service connection is present or absent.

8.3. Spaces crossed by HIALs

The highly integrated axial lines (HIAL) cross multiple spaces on their way. Considering that these lines represent the likely visual axes of the house (3.3.2), the crossed spaces are also the spaces more likely to be seen through. In this section, the passage of HIALs through the six major spaces are investigated. For this purpose, three qualities of passage were considered: *no line* passing, passing through *inside* (i.e. probably revealing crucial information), and passing beside the spaces (*side*) (see, 4.4.9 for more information on this labelling).

Hypothesis

It is possible to draw hypothesis based on the results of the previous section:

a. Considering the low presence DxL, SxL and DxK in IA1 (Figure 8.1 in Section 8.2.1), there are not many dining and living rooms in this subtype crossed through by an HIAL.
b. Regarding the higher presence of DxK and LxS HIALs in subtype IIA, it is expected that this subtype includes more kitchens crossed through by an HIAL.
c. Considering the high occurrence of DxL in IB2 (80%) and that the hall is always between dining and living rooms in this subtype, the hall will be significantly crossed through by HIALs.

Results

Figure 8.3 shows the percentage of houses in which a major space is crossed by an HIAL across the subtypes. The darker tone indicates the HIAL crossing from the middle of the space while the lighter tone represents the HIALs passing through a side of the space.

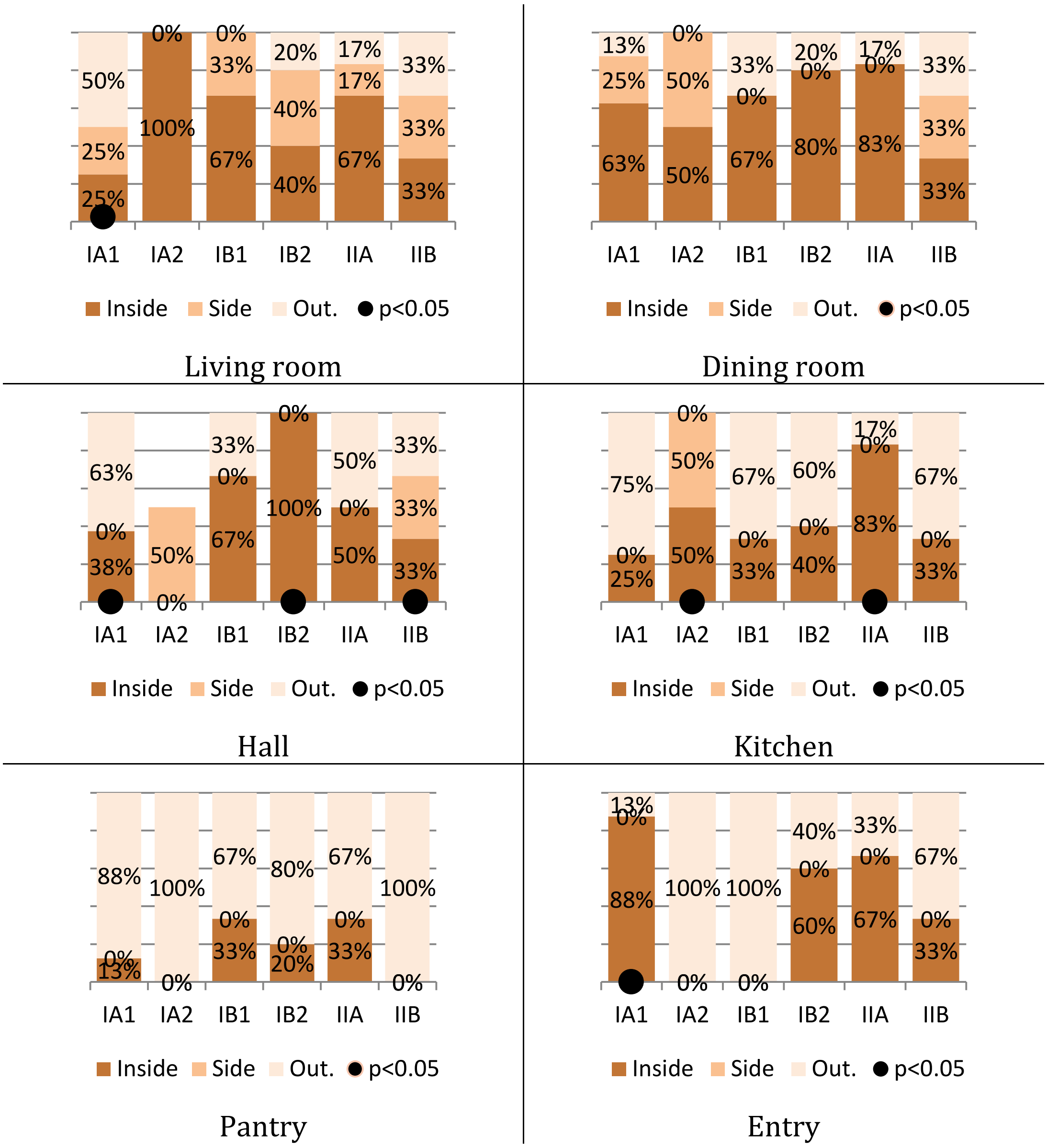


Figure 8.3. The percentage of houses with a high integrated axial line passing marked spaces.

The dining room has the highest number of HIALs in most of the subtypes, reflecting the findings of Chapter 5. The results do not support part of hypothesis (a) as there is no significant difference between the dining rooms in the subtypes. On the other hand, the other part of this hypothesis for the living room is supported with the significantly lower number of living rooms passed through in subtype IA1.

The percentage of HIALs passing through the kitchen differs significantly between IA1 (25%) and IIA (83%). The latter value supports the hypothesis (b). Two other differences are observed in the results including higher figures for the halls (100%) in IB2 and for the entry (88%) in IA1. The former supports the hypothesis (c) while the latter remains unexplained by the generic layout of subtype IA1.

8.4. Significant intersections

The highly integrated axial lines (HIALs) indicate important paths of movement and view. Therefore, the intersections of such lines reveal points where those views and paths meet. This suggests that such points may have a significant impact on surveillance and choice of paths (see 3.3.2). Nevertheless, just being an intersection of two HIALs does not guarantee significance. Instead, the integration values (in a dual axial graph, see 3.3.2) were considered. In any case, the highly integrated intersections (HIX) are usually the intersections between highly integrated axial lines.

Hypothesis

We can expect the rooms which host more than one HIAL are likelier to host HIXs as well:

a. Considering that the two most frequent HIALs (DxK and DxL) pass through the dining room, this space is expected to have more HIXs as well. This does not differ significantly in the subtypes.
b. The spaces with higher connectivity may also have more HIXs, as there is probably more density of intersections in them, in all subtypes. Therefore, we can expect the hall to have a higher percentage of HIXs. This would be more visible for IB2, regarding its perfectly central hall.

c. On the other hand, the living room, kitchen, entry, and pantry are less likely to host HIXs. This would be more visible for the living room of IA1 which is not often crossed through by HIALs.

Results

Figure 8.4 shows the presence of highly integrated intersections (HIX) in the major spaces across the six subtypes. Each graph shows the percentage of houses among subtypes which have HIXs passing through a specific space.

Figure 8.4. The percentage of houses with a high integrated intersection (HIX) in the major spaces.

As expected (a), the dining room hosts most HIXs in all subtypes, without a significant difference between them. The hall and living room compete for second place. Supporting the hypothesis (b), the hall in IB2 hosts significantly more HIXs (100%). The generally lower HIXs in the kitchen and pantry follows the expectations, while there are more HIXs in the entry than expected.

Contrary to the expectation from the third hypothesis (c), the results show no presence of HIX is the living room of IB2 (not IA1). Compared to the Victorian houses with their lower levels of crossing living rooms by HIALs (see 5.8, Figure 5.14), this result may suggest that the subtype IB2 has more similarity to the Victorian houses in regard to the presence of HIXs in the living room.

Nevertheless, in general the location of HIXs are less likely to be related mainly to the subtypes and so the differences in the results would stand for other factors which are out of the scope of this analysis.

8.5. Summary

In this chapter, three variables of axial mapping are analysed. The results showed limited impact of the subtypes, service connections, and fireplace position on the measures. It can be said that axial measures are the least likely to be predicted by layout. This resonates with one of the main criticisms raised by Ratti (2004), that this definition of axial lines (as used by depthMap) may be too sensitive to minor geometrical variations.

Nevertheless, there were patterns identified between subtypes and the crossed spaces. However, due to the complicated nature of the axial mapping, as well as the small data set, it is not feasible to draw an objective conclusion on the working mechanism of these patterns. In general there were two important findings in this chapter:

- Subtype IIA has the most axially important connection between the living room and the service zone. Considering the undesirability of this connection in the era in which these designs were built, it is possible to question the efficiency of this subtype in fulfilling this cultural value of its time.

- Subtype IB2 has the lowest rate of inclusion of axial lines and intersections in the living room, making it resemble the Victorian house. Nevertheless, such a finding implies that the living room does not provide a decision-making role in the IB2 houses.

9. Conclusion

9.1. Introduction

The present thesis provides a quantitative analysis of Prairie style houses to complement and improve the current understanding of their topological features. The quantitative analysis in this research is based on the principles and techniques of the theory of space syntax – an established theory for the topological analysis of the built environment. This research offers a valuable extension to past space syntax research which has tried to provide more objective and mathematically-supported insights, or to explore new understandings of historical designs.

This final chapter integrates all of the results of the thesis (Chapters 5 to 8) and highlights the findings and contributions in a wider perspective. This chapter is structured in five sections. First, it summarises the research steps and methodology and the general outline of results. Second, it discusses the findings of the comparison between Prairie and Victorian houses. Third, it highlights the findings on the topological features of Prairie style houses. Fourth, it discusses the contributions of the thesis to the use of space syntax in this research. Finally, it outlines the limitations and future directions of this topic.

9.2. Summary of the research process

The main goal of the research is to complement and improve the understanding of Prairie style houses by using a more objective methodology. The focus of this thesis is on the spatial properties or topology of the houses. This goal further extends in two levels:

- The first level includes the understandings of Prairie houses relative to their preceding and contemporary houses of Victorian era.

- The second level pertains to the improvement of the understanding of Prairie houses *per se*.

The methodological premise of this research is that the theory of space syntax has the potential to provide the objective framework to fulfil the above objectives. Hence, its techniques and interpretations were adopted as the main method for examining the topological features of the Prairie style houses. The research used space syntax techniques to address the two objectives (and thus the main aim) through two respective stages of research:

- Stage I is based on wide acknowledgement of Prairie houses as an innovative trend of residential architecture in its time and geographic context. Accordingly, this approach used the space syntax method to examine and verify a number of the claimed innovations by comparing Victorian and Prairie houses. The findings of this stage are discussed in Chapter 5.
- Stage II of the research aims to explore and identify topological features of Prairie houses through various techniques of space syntax. The latter exploratory approach also aims to understand the similarities and differences between Prairie houses in regard to their topological features. However, due to the high level of differentiation and individualism in Prairie houses, the analysis focuses on identifying regularities between collective layouts (types and subtypes) of the houses. The findings of this stage are presented in Chapters 6, 7, and 8.

The findings of each stage fulfil the respective objectives by verifying or clarifying the claims of the literature, and exploring or discovering different facets of Prairie houses. In the next two sections, the outline, results, and findings of the two approaches are discussed, respectively.

9.3. Findings of Victorian-Prairie comparison

One of the reasons for the wide praise of the Prairie style within the architectural community is that it contributed to design by introducing and excelling in various innovative features. The first set of analyses in this research aims to examine the topological aspects of such features with space syntax techniques. However, the findings of the analysis (Chapter 5) were mixed, especially in regard to the visual integration of the house or its individual spaces. Table 9.1 shows the summary of findings regarding the claims.

Table 9.1. The summary of measured claims of Prairie innovation in this research.

Claims	**Findings**
Holistic space or "wholeness"	The possibility of indirect support when considering the visual importance of the hall and organisational significance of the living room. Otherwise, the claim was not supported.
(Visual) integration of rooms into the house	Only the hall showed a significantly higher connectivity, while the claim was unsupported for other spaces and by other measures.
"Inwardness" or increased social interaction in interior spaces.	This claim was supported based on defining inwardness through the convex integration.
More ringed circulation	Partially supported.
Difference in desirability of *interspatial* connections	This idea was generally supported by the presence of sequence of the order of visual connections in the house.
Visually focal fireplace	Only some of the houses' fireplaces were visually integrated.

There are two ways to interpret the mixed nature of results within the limited scope of this PhD thesis. Firstly, it is possible that the examined claims were not completely related to or measurable by space syntax techniques. The argument for this issue may highlight the importance of the cognitive features of shapes rather than their gross geometry which is the focus of space syntax. Features such as the treatment of corners (both in plan and section) and fireplace (central and outstanding) might have had a puzzling yet enlightening effect on the inhabitant of the house, or even on the mid-1900 architectural historian. This effect would have broken the mental image of room – rather than its visual entity – as a box, an image they had been used to.

The other way to interpret the results may consider the reason behind their mixed nature as that the spatial claims in the literature were only applied to limited aspects of the topology, or only to a number of Prairie houses, but then extrapolated to the whole of the style. For example, when the literature speaks of "visual integration", it may only be valid for a direct visual significance that can be represented by isovist area, not the measure of mean depth.

This issue has two contributions to the study of the Prairie style:

- First, although the contradictory findings do not necessarily refute the spatial claims in the literature, they are capable of outlining new understandings of the Prairie style within the scope of space syntax. For example, the findings show that the two styles do not differ from each other in regard to purely visual holism, or indirect visual integration of spaces (AMD and SMD measures).
- Second, the study demonstrates the complexity of dealing with such claims in the context of Prairie houses. Considering that the space syntax measures did not capture the claims of visual integration, it may be granted as implicit support for studies (e.g., Hildebrand, 1991) which propose other dimensions to these claims.

The latter implies that the present study has been able to clarify what aspect of the topological claims might have been the subject of the literature. An example for this implication is the case of inwardness (Section 5.5). Inwardness (and similarly used words in the literature) can have had two interpretations. One interpretation is drawn from the disposal of the middle-Victorian visitor-oriented social spaces of the late Victorian era. This interpretation points to the usefulness of Hanson's method (1998) by the consideration of inwardness as the contrast between visitor-inhabitant and inhabitant-inhabitant relationships. The other interpretation is based on the related concept of the family gathering or of bringing family together (Maddex, 2000). This interpretation requires the use of ordinal integration values. However, only the second position was supported by space syntax measurements (as living room, and entry had higher integration ranks in a higher percentage of houses in the Prairie style: +30% and +34%, respectively).

Another aspect of this clarification is the capacity to explain the mechanism, or reason, behind a claimed feature. One example is the potential explanation of holistic space by related features of the core spaces of the living room and hall. Similarly, a potential reason for the higher isovist area or connectivity of the Prairie hall (+9%) is identified as its adjacency with a much larger living room (+8%). Another example is the experimental measure of interspatial depth that may explain how the undesirability of the service-social relationship was addressed both syntactically (1.6+ turns) and visually (90+ degree turn).

An important contribution of this thesis to understanding the Prairie style is an identification of genotypical tendencies in both Victorian and Prairie houses, and the similarities and difference between them. In both styles, a particular order of integration values as *(hall) > dining room > kitchen, parlour* was relatively common (53% for Victorian houses) (Section 5.5.2) while the same sequence was less present in the Prairie houses.

Similarly (in Section 5.5.2), the study found several recurring visual genotypical patterns. The most intriguing pattern was the sequence of *L-D* < *D-K* < *L-K* in Victorian and Prairie houses (syntactically 86% and 74%, and angularly, 53% and 45%, respectively) showing more uniformity in Victorian houses in addressing the perceived desirability of visual connections in the house. Meanwhile another sequence of *E-L* < *E-D* < *E-K* (74% in Prairie houses) and *E-D* < *E-L* < *E-K* (67% in Victorian houses) demonstrate possible different presentations of living (parlour) and dining rooms to a visitor in

Victorian and Prairie houses. The higher interconnection of social spaces in both styles is comparable to similar findings by Amorim (1999) about pre-modern and modern houses in northeast Brazil.

The study also identified a number of Prairie houses which feature the greatest departure from and closest similarity to the average Victorian and Prairie house (see Section 5.9). While no house featured a strong departure or similarity to either of styles, we could argue that the houses for Fuller and Kellogg (Figure 9.1) had relatively more Victorian features. On the other hand the houses for Adams (scheme #1) and Baker (Figure 9.2) had the most combined claimed Prairie features and similarity with the average Prairie house.

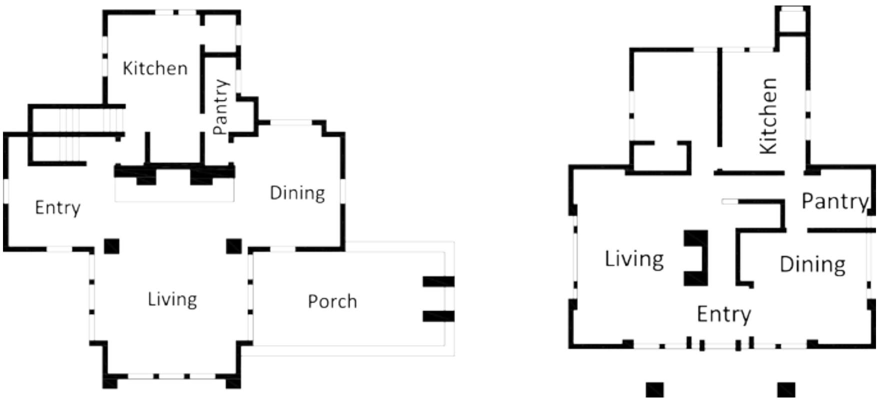


Figure 9.1. Houses for Kellogg (left) and Fuller (right).

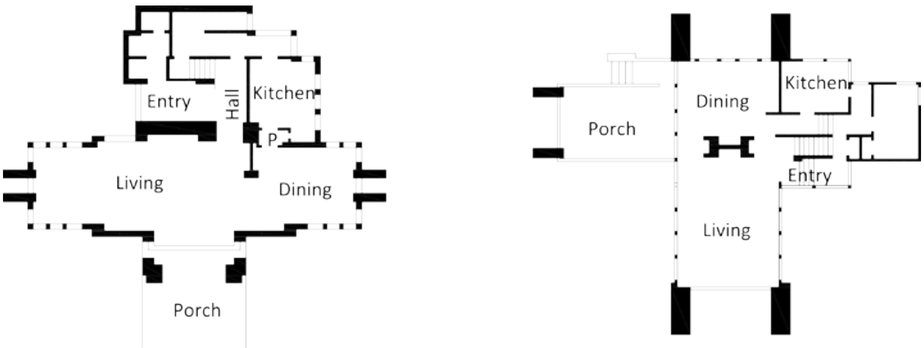


Figure 9.2. Houses for Adams (scheme #1, left) and Baker (right).

In conclusion, regarding the aim of the research, the findings of Stage I complement and strengthen some of the claims in the literature, but also are potentially able to explain why or in what aspect those claimed features are feasible. Similarly, some of the findings would help to narrow down the alternative explanations and interpretations of the claims in order to use a more appropriate method in future studies. This stage of study contributes to design history by extending or verifying the understanding of both Victorian and Prairie houses, and demonstrated a glimpse into their corresponding lifestyles. Another contribution to design history and pedagogy can be the new insights into the long-established and frequently taught topics in design schools.

9.4. Findings of Prairie analysis

The second analysis of this research provides new insights in the differences and similarities between the spatial properties of Prairie houses. The findings of this analysis can be generally divided into two categories.

Firstly, the analysis identifies and measures in detail the broad difference between Prairie houses in regard to spatial form or topology, in addition to the widely-stated differentiation in their physical form. Previously, only a few differences were briefly noted without further implication of those differences on the visual settings of the house (e.g., the position of fireplace on the L-D connection by Pinnell, 2005). Nevertheless, this finding contrasts to one of the recurring themes of the literature that is to propose a unifying explanation of the style (e.g., Hildebrand, 1991; Laseau & Tice, 1992; Dawes & Ostwald, 2014).

A particular example of why this distinction is important for understanding Prairie houses comes from combining the two stages of the research. Table 9.2 summarises the findings of how the subtypes measured against the average Victorian houses. The findings are marked by "significantly Prairie" (■) which indicates that the results for a measure were supportive of the claims of literature. The label "relevantly Prairie" (o) indicates an observable but non-statistical support for the claims, and the label "more Victorian" (x) represents results which significantly contradicted the claims.

The interesting point about the table is that the expected features (claims) are not collectively verified for a same subtype. For example, the subtype IB2 shows an overwhelming similarity to that which the literature considered to be the visual features of the Prairie house. On the other hand, it fails in two other claims: it has the least "inward" (integrated) living room and the least visually integrated fireplace. The subtype IB2 also has a large number of cases which featured the ideal physical characteristics of the Prairie house: perfect cruciform, open plan and a large independent entry (Figure 9.3), although its fireplace is not centrally located. In contrast, the subtype IIA also has several perfectly cruciform houses with central fireplace but features the highest resemblance to the Victorian topology.

The importance of this finding is that it draws a distinction between the different types of Prairie ideal characteristics which had not been made clearly (if at all) in the literature. The finding may suggest that some of these features are difficult to gather together in one house or type, or the features could even have competed with each other. Nevertheless, the finding of this distinction is based on a small number of cases and the limited interpretative scope of space syntax in this study.

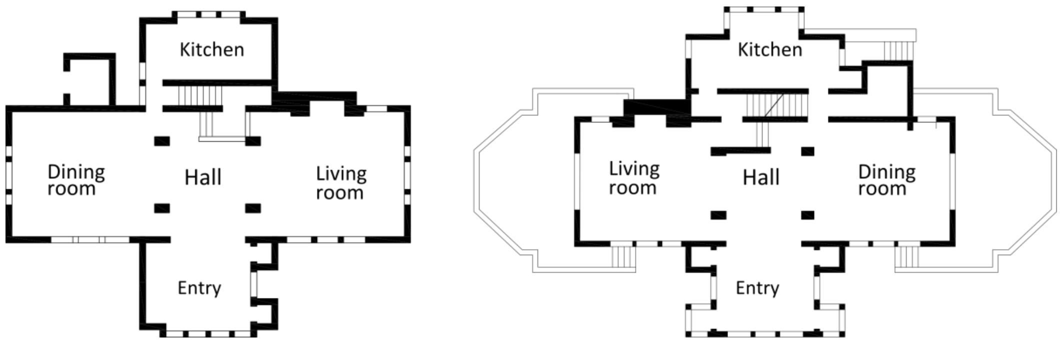


Figure 9.3. Two examples of IB2 subtype: Walser house (left), DeRhodes house (right). Plans are adopted from Futugawa (1987a).

Table 9.2. The subtypes of Prairie style, compared to the average Victorian house under space syntax measures. Only the measures in which a difference or similarity was observed are listed (the grey shade is only for a better legibility of the table).

Measures	Spaces	Sections/ Figures	Types IA1	IA2	IB1	IB2	IIA	IIB
Integration	Living room	6.3.1/6.5				x		
	Dining room	as above					x	
	Kitchen	as above					x	
Isovist area	Holistic	7.2.1/7.2		■ x[1]		■ x[1]		
	Living room	7.3.1/7.8				■		
	Dining room	as above		■		■		
	Hall	as above				■		
	Entry	as above					■	
SMD	Holistic	7.2.1/7.3				■		
	Hall	7.3.1/7.10				■		
	Entry	as above				■		
AMD	Holistic	7.2.1/7.4				■		
	Dining room	7.4.1/7.16				■		
	Hall	as above				■		
	Kitchen	as above					■	
	Pantry	as above	■					
	Entry	as above			■	■		
SID	L-D	7.6.1/7.23				o	o	
	L-K	as above			o			
	D-K	as above	o	o	o	o	o	o
	E-K	as above	o	o	o	o	o	o
	E-D	as above			x			o
AID	L-D	7.7.1/7.28				■		
	L-K	as above			o	o	x	
	D-K	as above			■	■		
	E-L	as above			o	o		
	E-D	as above			x			■
	E-K	as above	o	o	o	o	o	o
Focal fireplace		7.8/7.36	■			x		x
HIALs	Living room	8.4/8.4				x		
■ (significantly Prairie)[2]			7%	7%	7%	43%	7%	3%
o (relatively Prairie)			10%	10%	20%	20%	13%	13%
x (more toward Victorian)			0%	0%	7%	10%	10%	0%

[1]. Depending how the holistic isovist area (IA) is interpreted. If higher IA is taken as higher holism, then these subtypes are more Prairie, while if it is taken against "mystery", then these subtypes should be regarded as less Prairie.
[2]. The percentage figures are considered for higher IA as a positive Prairie feature.

The second category of findings is the different degrees of influence on the topological properties by the selected features of layout (types, subtypes, or service connections). In general, the findings point to three possibilities of the layout's influence on the value of topological measures:

- Topological measures which are influenced by some of the selected layout features. For example, the placement of the fireplace was significantly influential on many of the visual measures in the subtypes of Type I.
- Topological measures which are universally present in the style and so unaffected by the differentiations in layout (e.g., organisational integration of the hall).
- Topological measures which are influenced by features not identified in this thesis. For example, visually significant intersections were distributed between the subtypes in a way that no significant difference was found between them.

These findings address the third objective of the research – to understand the reason for the existence of the identified topological features in Prairie houses. Although the findings are limited due to the complexity of Prairie layouts, they are still able to identify several pattern of relationships between layout and topological features.

In general, this thesis provides various new perspectives to understand not only the spatial properties of Prairie style houses, but also possible design treatments (layouts) which had led to these properties. These finding would help researchers to draw a more comprehensive picture of the style, and its relationship with contemporary designs. In addition, the findings will improve the understanding of the relation between the design elements and topology of the houses. These findings could be used to understand the design process of the houses as well as to reproduce the designs through generative processes.

9.5. Contribution to space syntax

The main contribution of this study to the field of space syntax is a major application of space syntax theory and techniques involving forty-two houses. This application demonstrates the usefulness of this theory for analysis of spatial property in residential buildings. Specifically, this study identified possible connections between the features of physical form and the values of the topological parameters. Regarding the three mapping approaches of space syntax (convex, axial, and isovist mapping), the study found that the axial mapping showed the least correlation with the selected variations of form (Chapter 8). This is not surprising as the axial map has the highest sensitivity to details of the plan, a feature with has been considered a limitation of the mapping, especially in buildings (Ratti, 2004).

On the other hand, convex mapping is mainly influenced by the positioning of the connections between the service areas and other rooms in the house (Chapter 6). While this finding *per se* is also understandable regarding the mechanism of adjacency graphs, the relationship between such connections and the layout of the building is the intriguing part. The convex mapping of Prairie houses shows that the programmatic organisation of the houses is significantly independent of their layouts, unless the layout makes certain connections geographically impossible (see Section 6.6). In other terms, the architect was freer to opt desirable connections between the spaces.

In regard to isovist mapping, the features of layout have more influence on the results (Chapter 7). Although, similar to axial mapping, some of the values are evidently unaffected by the selected layouts' variations – they are generally more traceable to layouts than the former. The findings suggested that these measures are influenced by both large scale layout variations (i.e. subtypes) and smaller scale variations such as fireplace or service connections.

Another contribution of this study to space syntax theory is to demonstrate the resourcefulness of this theory for addressing various features of topology which concern movement, visibility, and orientation. This study has used both commonly used “standard” techniques of space syntax (e.g., intelligibility, integration, inwardness, “genotypes”, etc.) and slightly modified variants of such techniques to fit the study’s purpose and context (e.g., normalised mean depths, interspatial depths, holistic visual measures, etc.).

Nevertheless, the study has also found limitations in the application of space syntax in this context. One limitation was that the findings of the techniques of space syntax could not always be compared directly without further abstraction (in this thesis it was excluding upstairs and outside space). Another limitation was the dependence of interpretation on initial definitions. For example, in this thesis, labels like “side” or “inside” were defined to represent certain occupation of the space. However, another starting point for labelling could have significantly changed the results.

9.6. Future directions

This thesis is a quantitative case study intended to enhance, clarify, and explore the existing knowledge of Prairie houses within a rigorous quantitative framework. Similar to any research methods, the scope is narrowed, in the case of this research, by two aspects: the selected quantitative method, and selected cases. In this section, the possible future directions and extensions regarding these two aspects are discussed.

The computational method of study was adopted from the theory of space syntax. The tenets of this theory have been supported by empirical evidence for analysing many aspects of the built environment. However, space syntax has a relatively narrow focus which has defined the scope of this thesis and contributed to the uncertainty of how to interpret the results, especially when they did not match the statements in the literature. This does not, however, undermine the validity of the results, but more the relevance or efficiency of applying them for examining the findings of the existing literature.

The scope of this study is also defined based on the selected cases in order to maintain the comparability between the cases and adjust for the timeframe of this research project. Hence the cases and the results of the analyses, only represent the simple form of Prairie and Victorian houses, not the whole of the Prairie style or Victorian design.

The two mentioned aspects of scoping in this thesis open a window for future improvements and extensions of the present research. In general, there are two possible future directions in the short term. The first is to further the findings of this research through other relevant methods. The second would be to include additional case studies to fill the gaps or uncertainties in this research. These two directions relate to the two aspects of scope – method and selected cases – respectively. Hereafter, different possibilities for each of these types are discussed:

- Two of the main findings of this research are about the ambiguity of interpreting the claims in the literature, due to the methodology chosen. The first ambiguity is whether some of the seemingly topological claims (e.g., holistic space and more integrated spaces) are not supported by the results or if these claims are not actually related to the gross topological features of the space. Future empirical or/and computational studies may shed light on this ambiguity. The second ambiguity is related to the extent of ideal features of the Prairie houses. Some of the ideals (convex-based integration, visually prominent fireplace, and visual inter-connectivity of spaces) are found to be sometimes conflicting with each other and unlikely to be present in a significant number of buildings, simultaneously. A future study on more Prairie cases might resolve this issue.
- It is possible to further the findings of this study by extending the cases. One outcome of this research is the mapping of genotypical tendencies of both convex and isovist results of the Prairie and Victorian houses. This finding can be used as a basis for a comparative analysis of other scales of Prairie style houses (e.g., with library, or other extended houses), Wright's later houses (Textile-block and

Usonian periods) and houses of the Victorian era (especially the inspirational works of Richardson and Price). Such extended studies will help to improve our knowledge of the life styles and design strategies of society of the late nineteenth and early twentieth centuries. A further finding of this research is the discovery of several correlations between the layout variation and the topological features in Prairie houses. A future extension would help to identify more layout features and design elements with computational evidence of their influence.

Within the scope of this PhD programme, this research has been able to capture several important features in the Prairie house and identify new, previously poorly understood properties of this approach. This fulfils the goal of the study – to enhance our understanding of the Prairie style. The research has verified some of the long-believed topological characteristics of the Prairie houses, it has identified the possibility of some inconsistencies in the literature and captured several important genotypical trends. Finally, it has demonstrated and analysed a less-known but prominent variety of topological variations of the Prairie houses.

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I. Plans of Victorian and Prairie houses

In this appendix, the schematic plans of the first floor for the selected Victorian and Prairie houses are presented along with the visualisation of the space syntax measurements. This appendix is consisted of two sections for the two styles respectively. In the first section, the Victorian houses are ordered based on their "plate" number in Cirker's *Victorian house* (1996). This section begins with the raw floor plans of the 15 houses and then the visualised results for each house is presented in a respective page. In the second section the Prairie houses are ordered alphabetically. Unlike the Victorian houses the raw floor plan of the Prairie houses are presented separately for each house with their respective result visualisations.

In all visualisations, the "warmer" colours represent the higher values. This means the red colour in convex and axial maps stand for higher integration while it stands for higher depth (so, lower integration) in visibility grids. Accordingly, the blue colour stand for the lower integration values in convex and axial maps and also lower depth in visibility grids (thus, higher integration). In the angular mean depth, the colour purple represent yet the lowest values. The only exception for this colouring scheme is in the primal axial map when there is a grey line (representing a fully connected line or $i = \infty$) or when all lines are green (the integration values of are all equal, usually $i = \infty$). The blank (white) areas in the convex maps or visibility grids indicate the excluded areas (as explained in 4.3.2).

The alphabetical labels on the floor plans represent the major spaces (L: living room, D: dining room, K: kitchen, H: hall, P: pantry, E: entry), in addition to the porches (T). The numerical label indicate the rest of convex/social spaces in the plan.

I.1. Victorian houses:

1. untitled cottage (Plate[1] 2)

2. Cottage at Monmouth Beach (Plate 5)

3. Cottage at Block Island (Plate 8)

4. $1800 Dwelling (Plate 9)

5. Swiss Cottage at West New Brighton (Plate 10)

6. $1200 Cottage (Plate 18)

7. Dwelling for $2500 (Plate 25)

8. Dwelling of Moderate Cost (Plate 27)

9. Dwelling of Moderate Cost (Plate 40)

10. Residence on Long Island (Plate 43)

11. Residence at Mount Vernon (Plate 49)

12. Residence at Bridgeport (Plate 52)

13. Suburban Dwelling (Plate 55)

14. Cottage at New Rochelle (Plate 60)

15. Residence at Edgewater (Plate 75)

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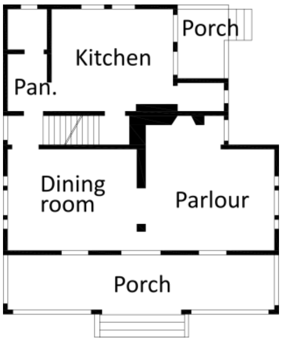
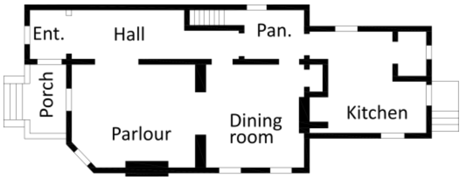
[1] . The plate numbers of the actual page numbers in Cirker, 1995.

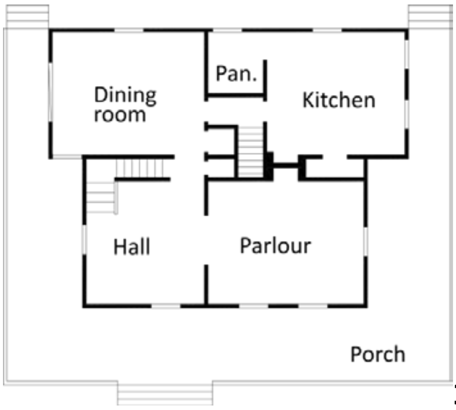
The floor plans of the selected Victorian houses



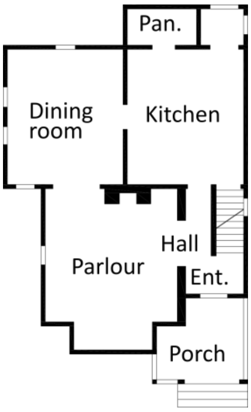
1. untitled cottage (Plate 2)



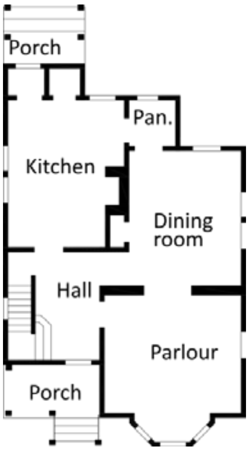
2. Cottage at Monmouth Beach (Plate 5)



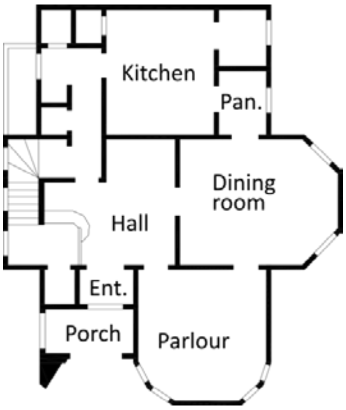
3. Cottage at Block Island (Plate 8)



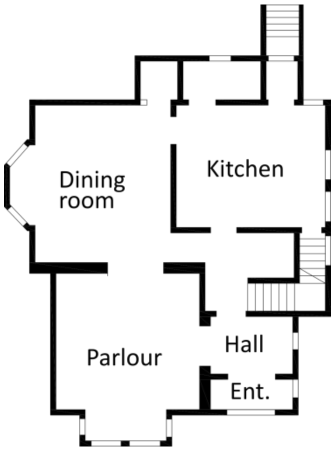
4. $1800 Dwelling (Plate 9)



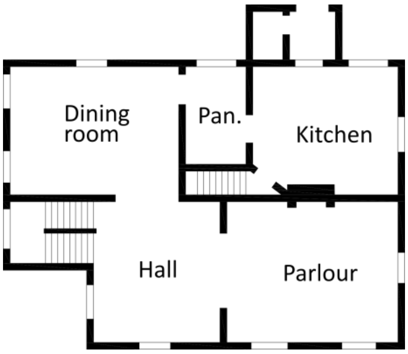
5. Swiss Cottage at West New Brighton (Plate 10)



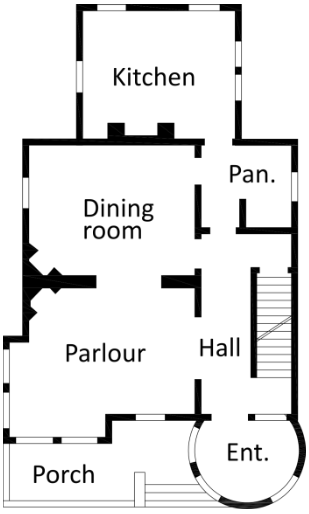
6. $1200 Cottage (Plate 18)



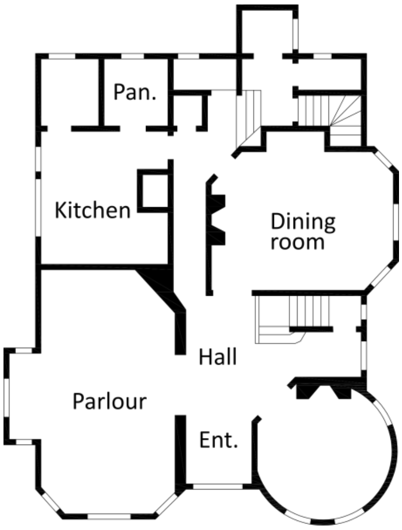
7. Dwelling for $2500 (Plate 25)



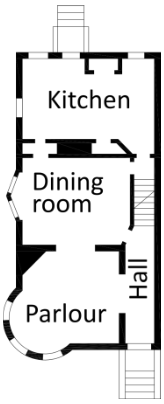
8. Dwelling of Moderate Cost (Plate 27)



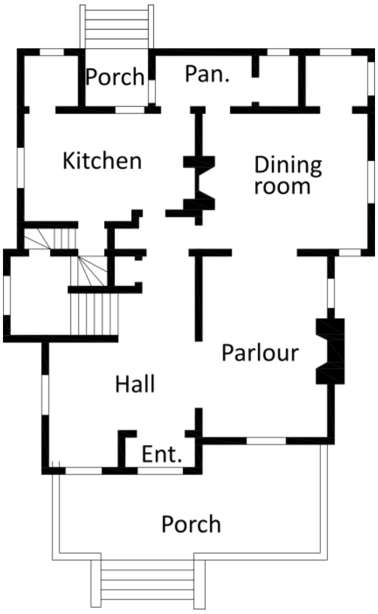
9. Dwelling of Moderate Cost (Plate 40)



10. Residence on Long Island (Plate 43)

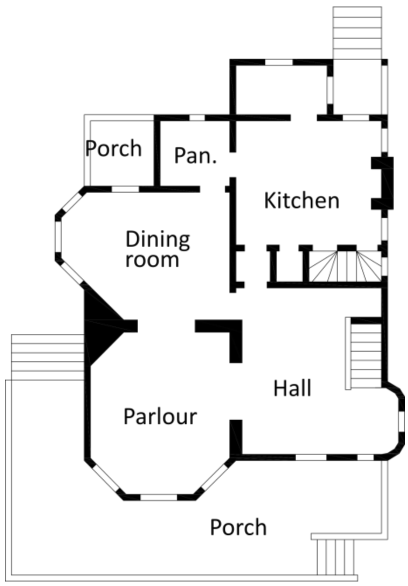


11. Residence at Mount Vernon (Plate 49)



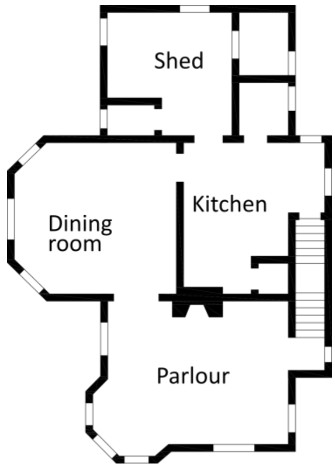
12. Residence at Bridgeport

(Plate 52)



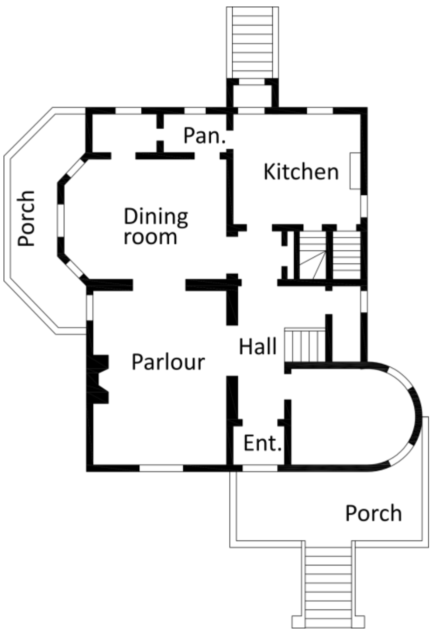
13. Suburban Dwelling

(Plate 55)



14. Cottage at New Rochelle

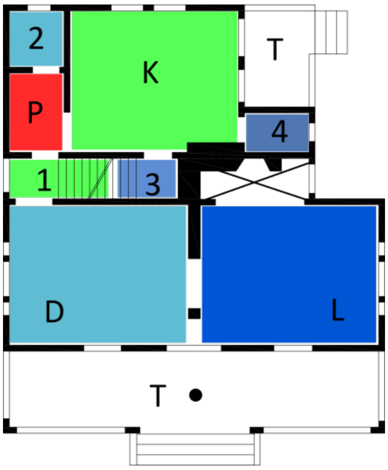
(Plate 60)



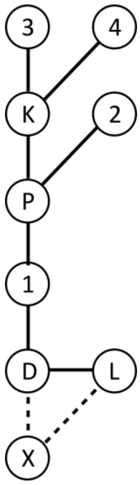
15. Residence at Edgewater

(Plate 75)

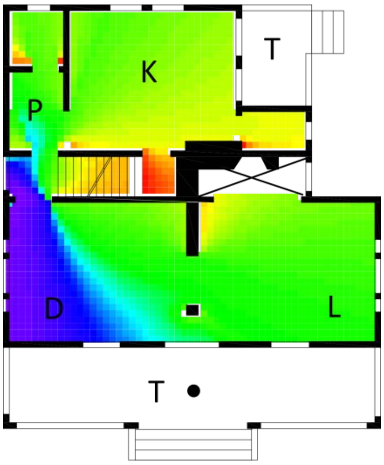
1. Untitled cottage (Plate 2)



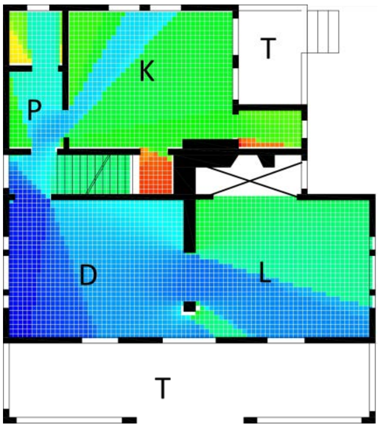
Convex map



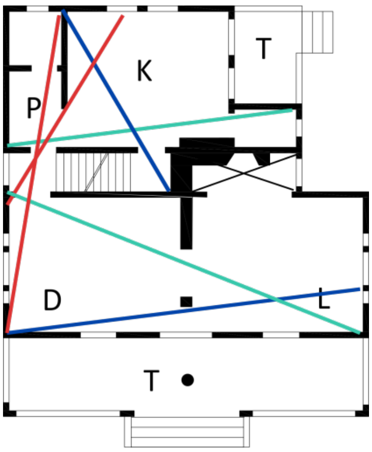
Justified plan graph



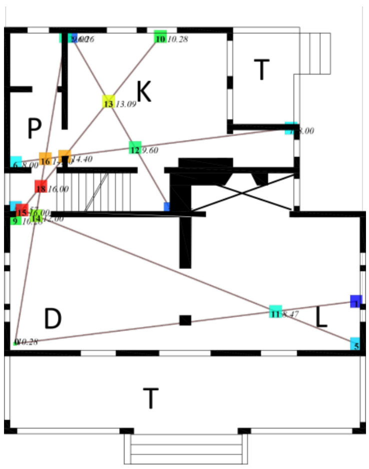
Angular mean depth



Step mean depth

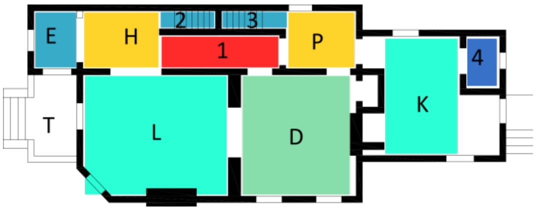


Primal axial map

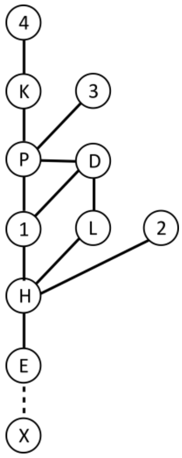


Dual axial map

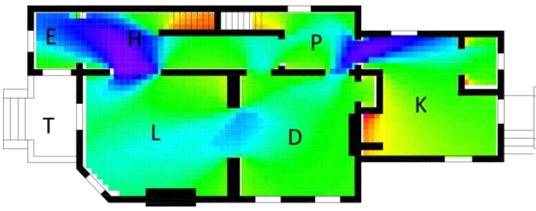
2. Cottage in Monmouth Beach (Plate 5)



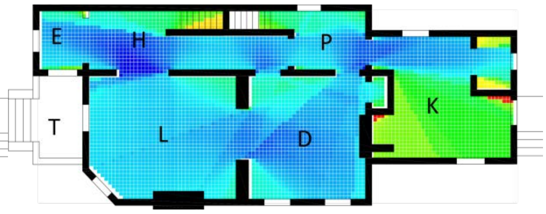
Convex map



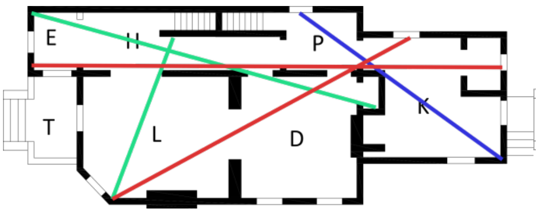
Justified plan graph



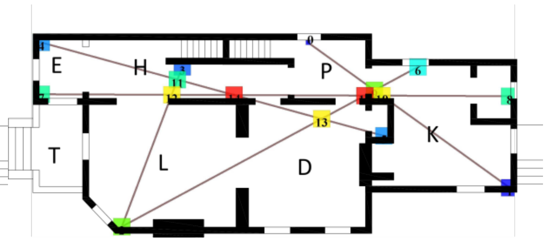
Angular mean depth



Step mean depth

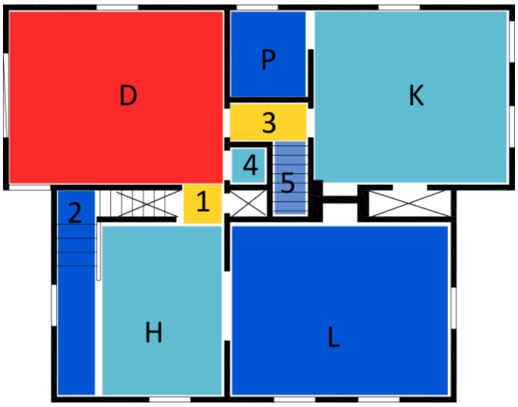


Primal axial map

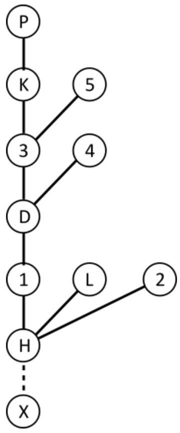


Dual axial map

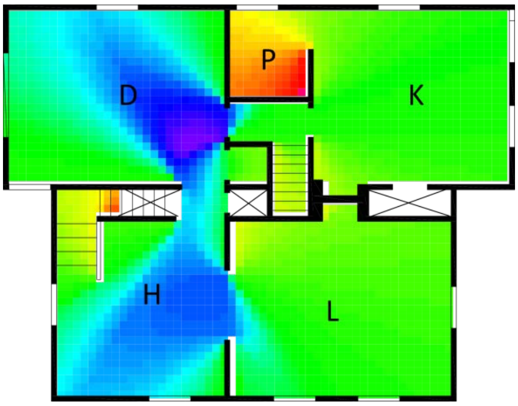
3. Cottage in Block Island (Plate 8)



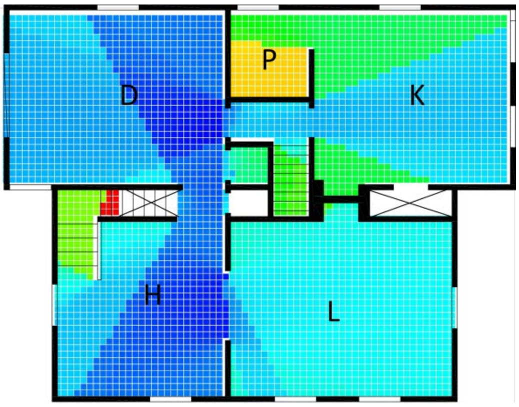
Convex map



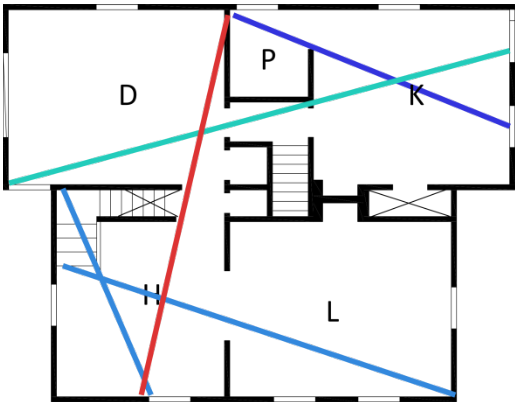
Justified plan graph



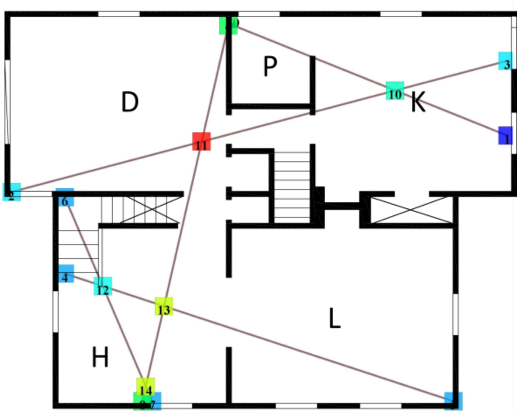
Angular mean depth



Step mean depth

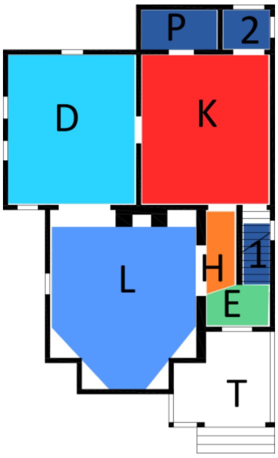


Primal axial map

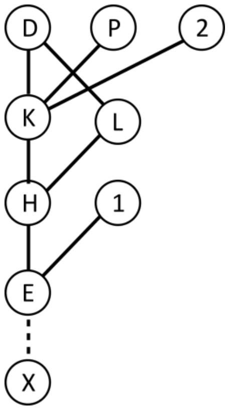


Dual axial map

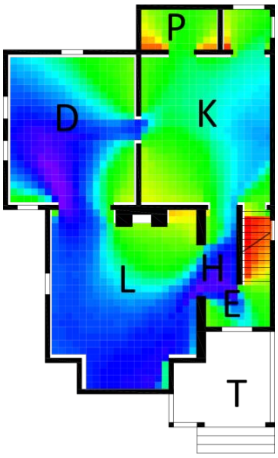
4. $1800 Dwelling (Plate 9)



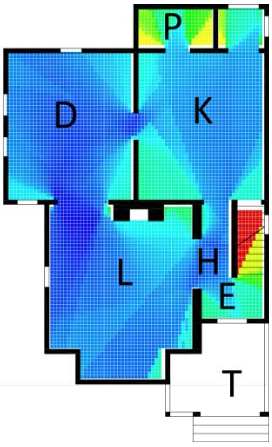
Convex map



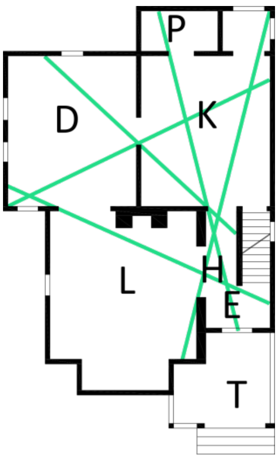
Justified plan graph



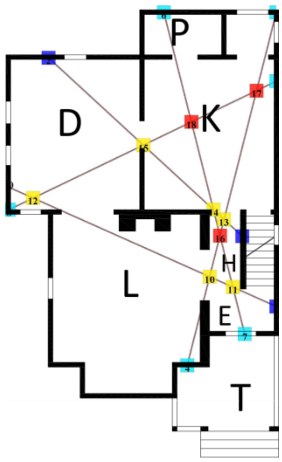
Angular mean depth



Step mean depth

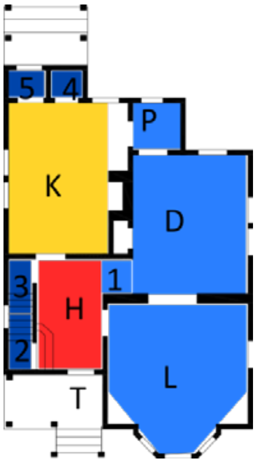


Primal axial map

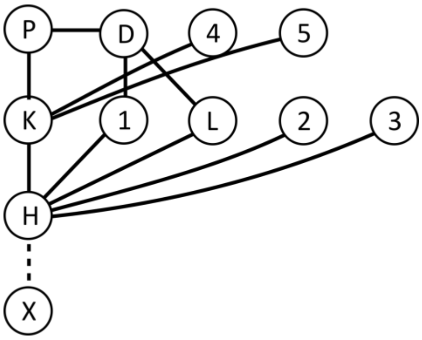


Dual axial map

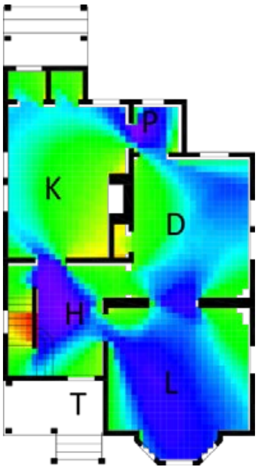
5. Swiss Cottage at West New Brighton (Plate 10)



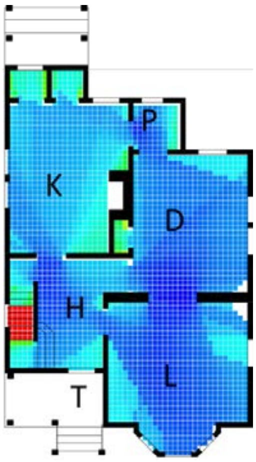
Convex map



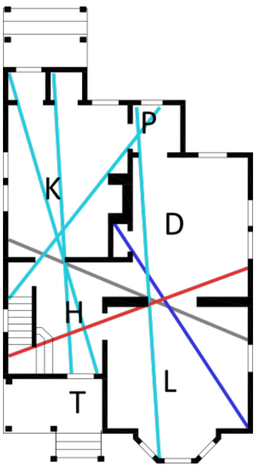
Justified plan graph



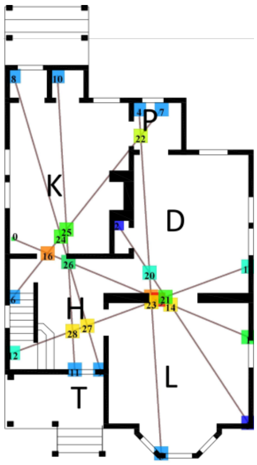
Angular mean depth



Step mean depth

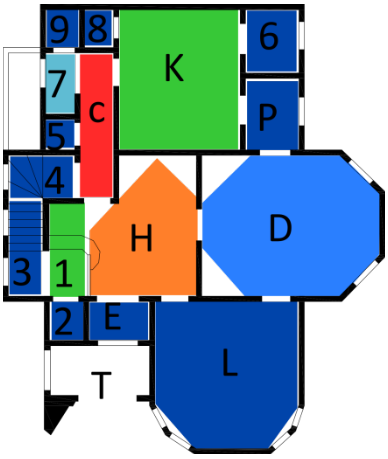


Primal axial map

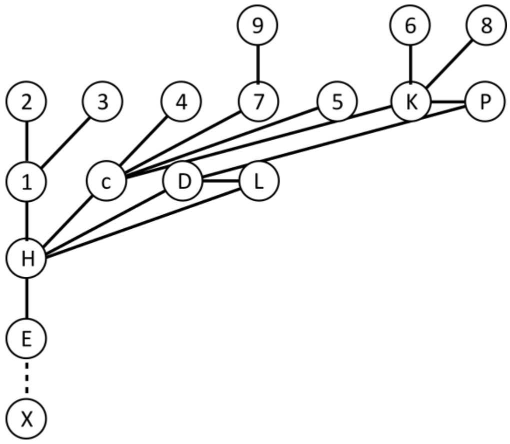


Dual axial map

6. $1200 Cottage (Plate 18)

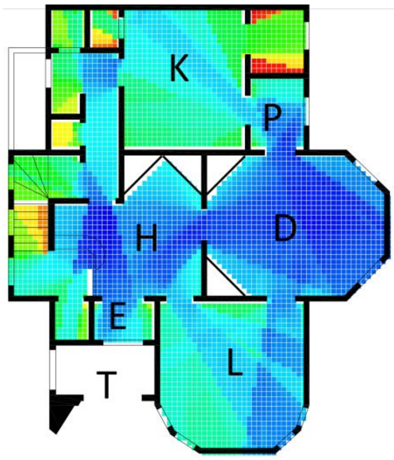


Convex map

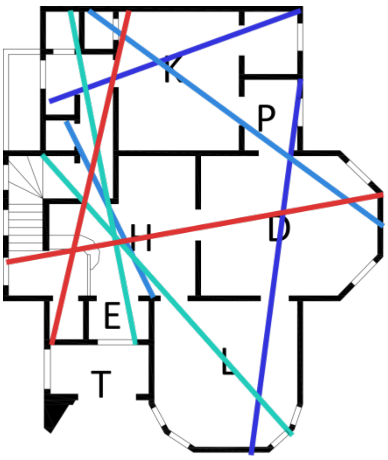


Justified plan graph

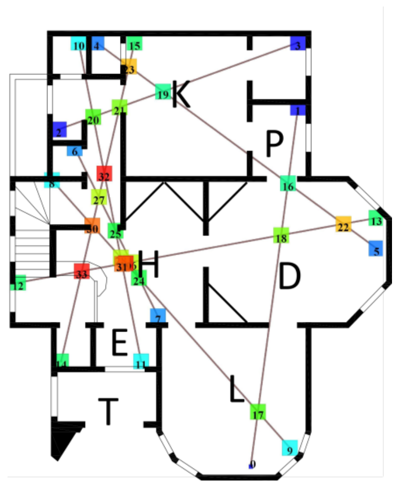
Angular mean depth



Step mean depth

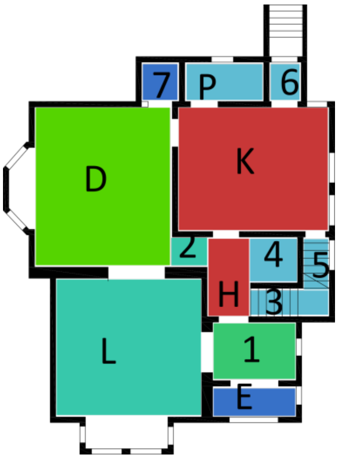


Primal axial map

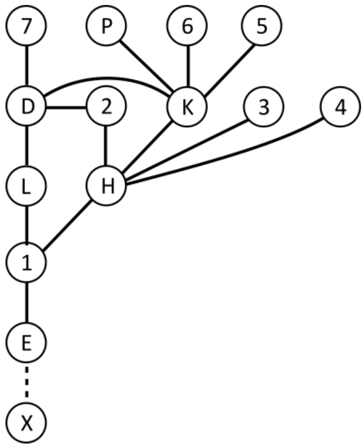


Dual axial map

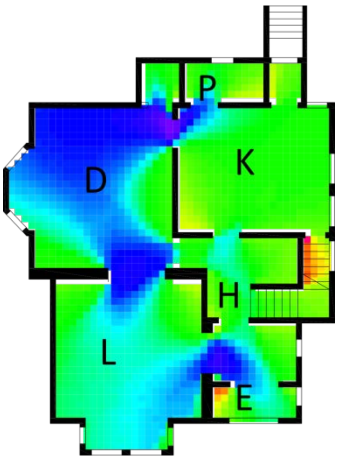
7. Dwelling for $2500 (Plate 25)



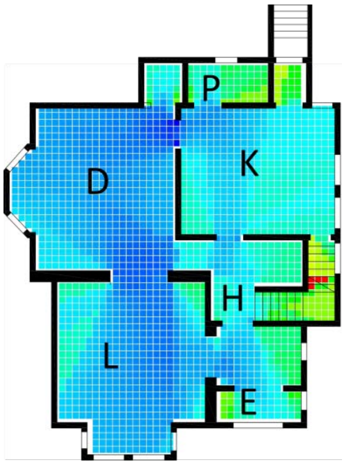
Convex map



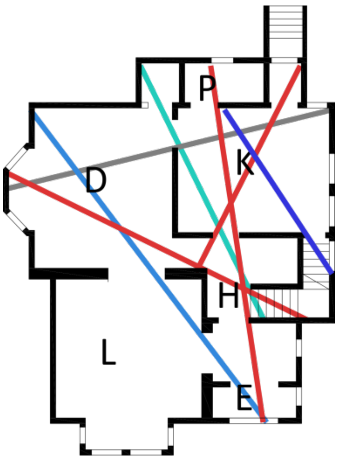
Justified plan graph



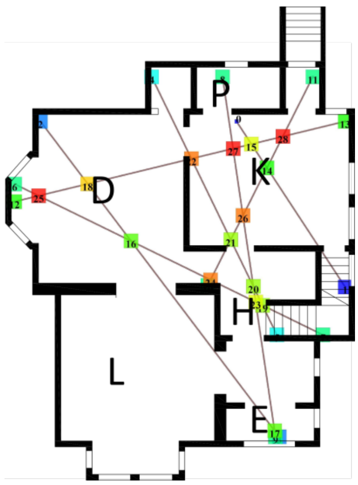
Angular mean depth



Step mean depth

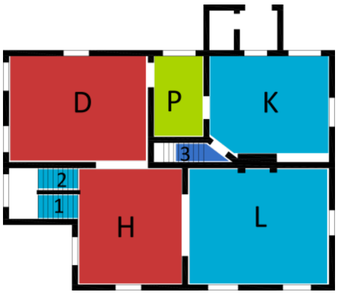


Primal axial map

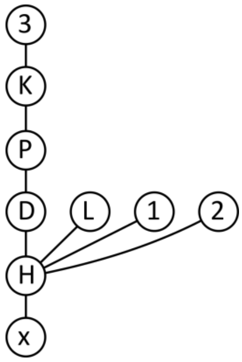


Dual axial map

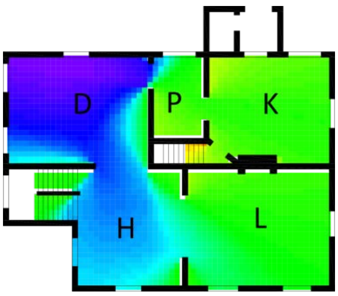
8. Dwelling of Moderate Cost (Plate 27)



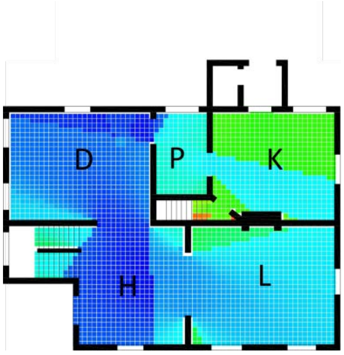
Convex map



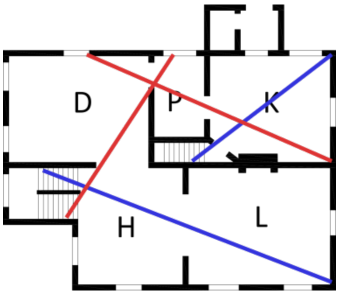
Justified plan graph



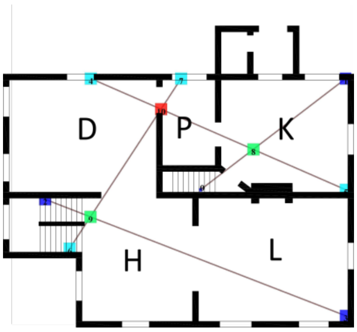
Angular mean depth



Step mean depth

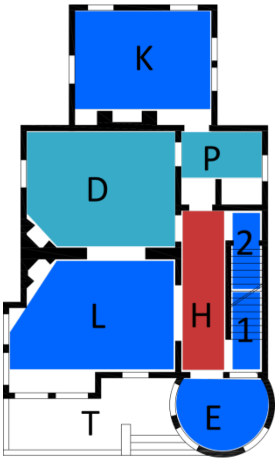


Primal axial map

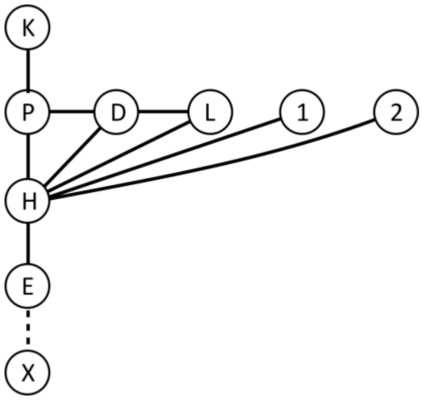


Dual axial map

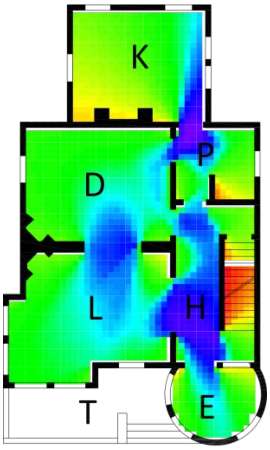
9. Dwelling of Moderate Cost (Plate 40)



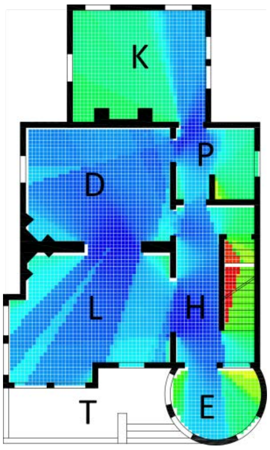
Convex map



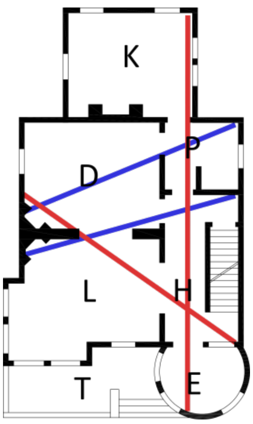
Justified plan graph



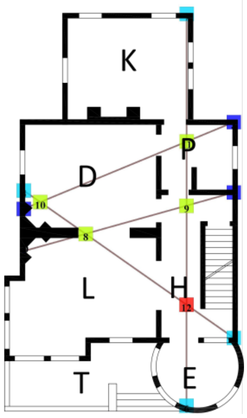
Angular mean depth



Step mean depth

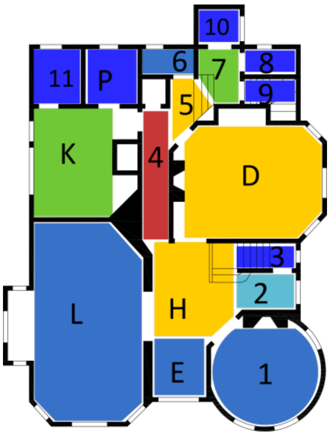


Primal axial map

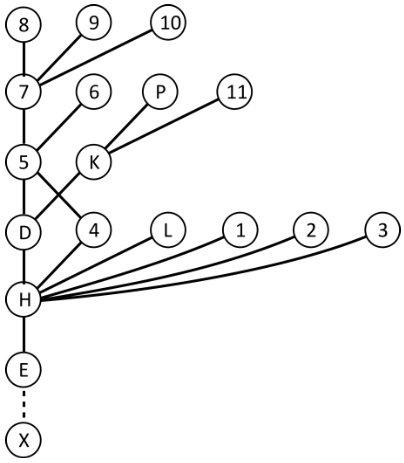


Dual axial map

10. Residence on Long Island (Plate 43)



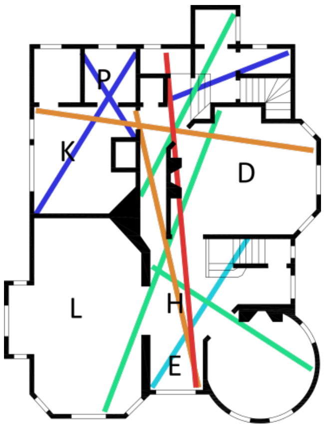
Convex map



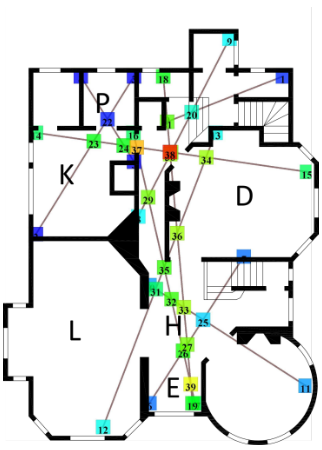
Justified plan graph

Angular mean depth

Step mean depth

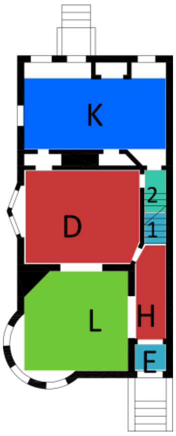


Primal axial map

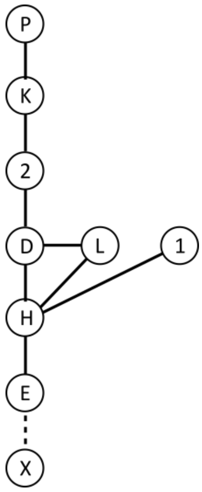


Dual axial map

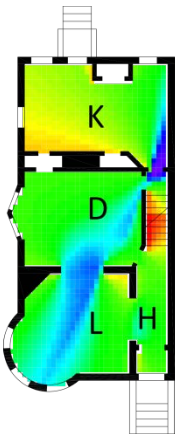
11. Residence at Mount Vernon (Plate 49)



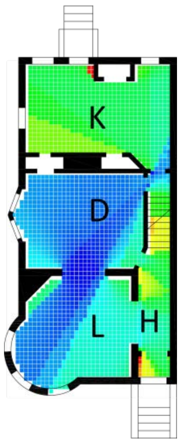
Convex map



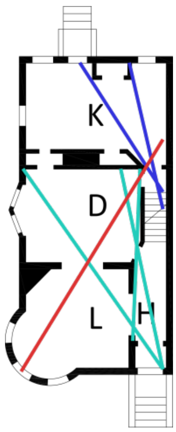
Justified plan graph



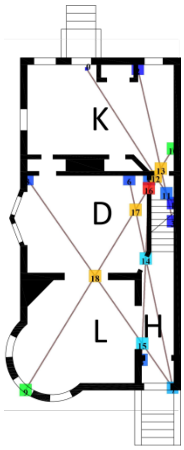
Angular mean depth



Step mean depth

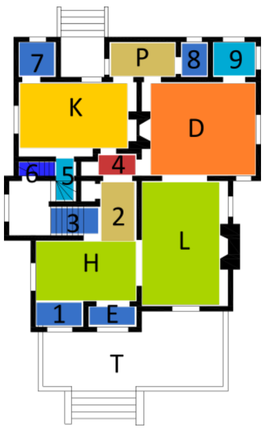


Primal axial map

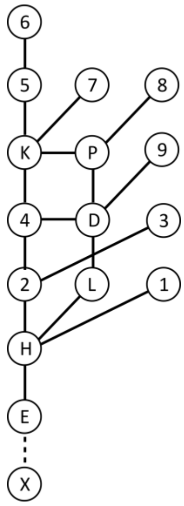


Dual axial map

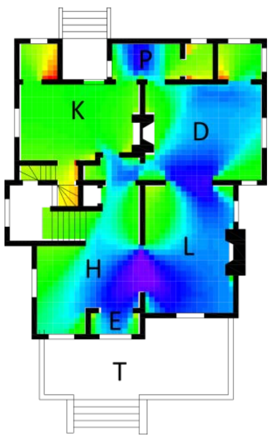
12. Residence at Bridgeport (Plate 52)



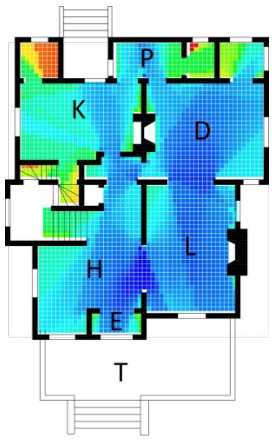
Convex map



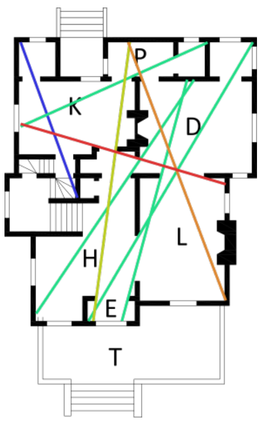
Justified plan graph



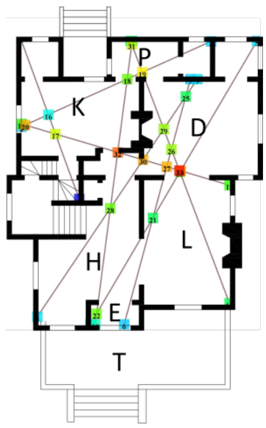
Angular mean depth



Step mean depth

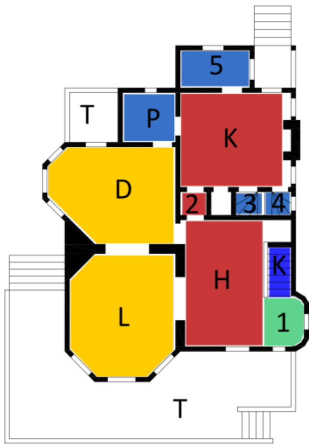


Primal axial map

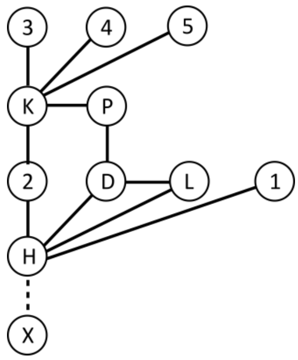


Dual axial map

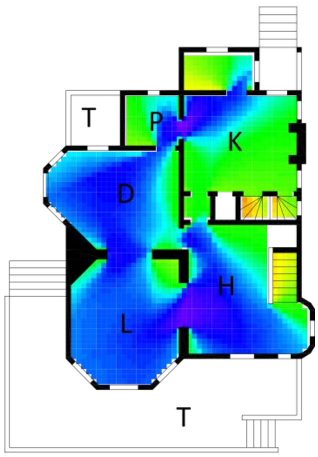
13. Suburban Dwelling (Plate 55)



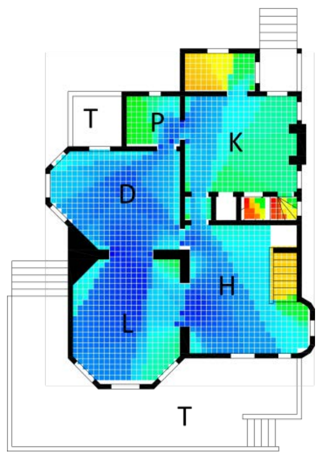
Convex map



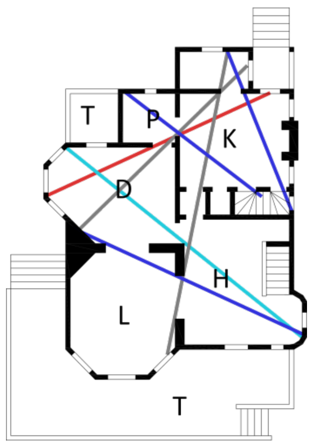
Justified plan graph



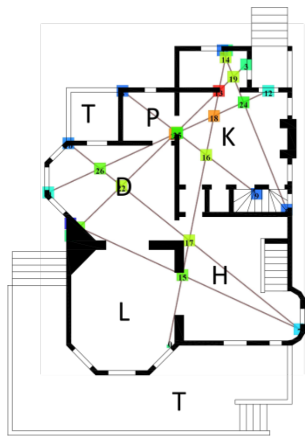
Angular mean depth



Step mean depth

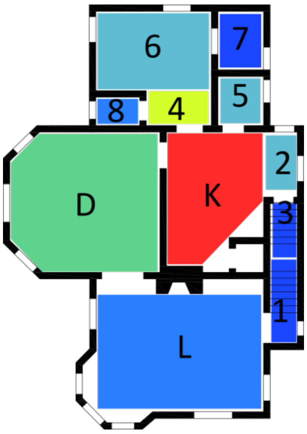


Primal axial map

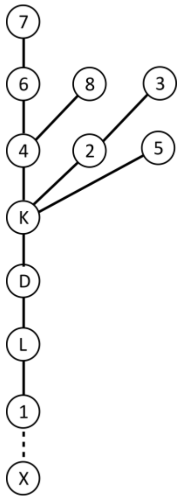


Dual axial map

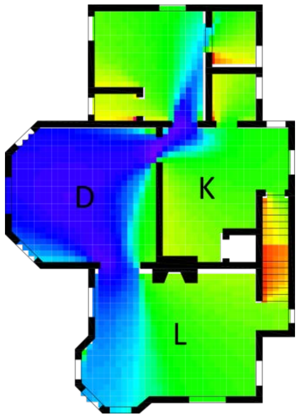
14. Cottage at New Rochelle (Plate 60)



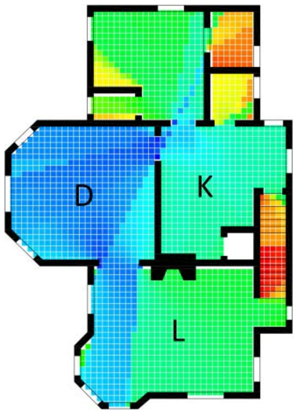
Convex map



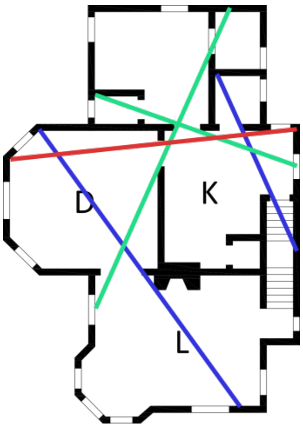
Justified plan graph



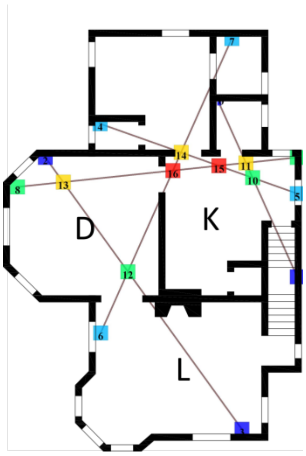
Angular mean depth



Step mean depth

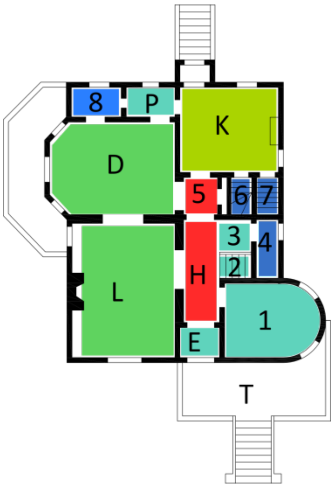


Primal axial map

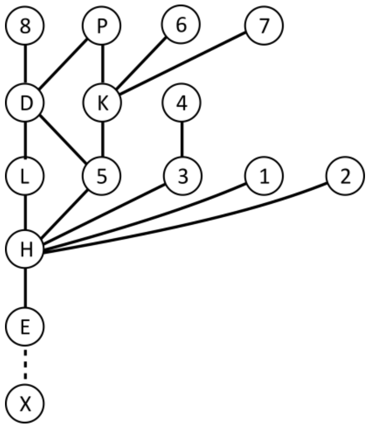


Dual axial map

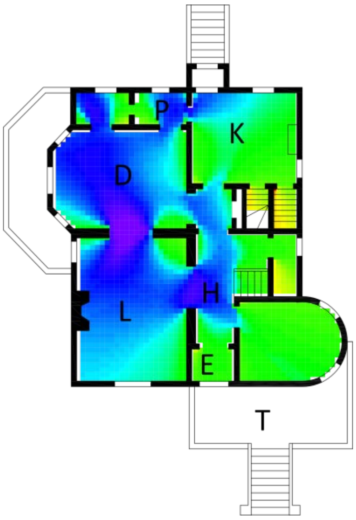
15. Residence at Edgewater (Plate 75)



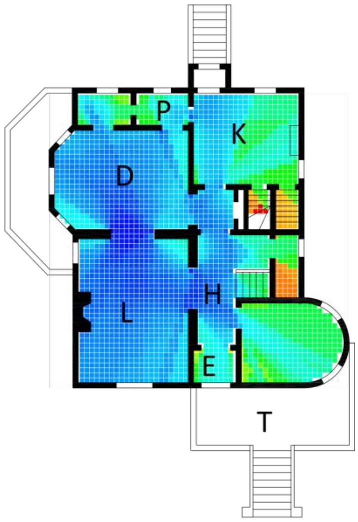
Convex map



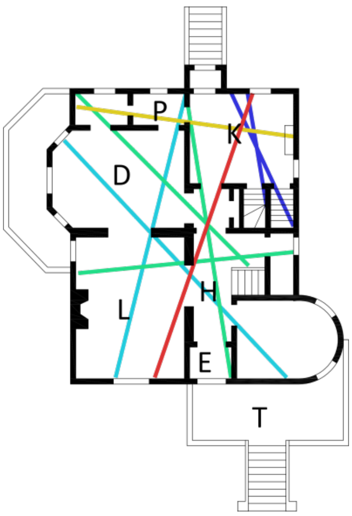
Justified plan graph



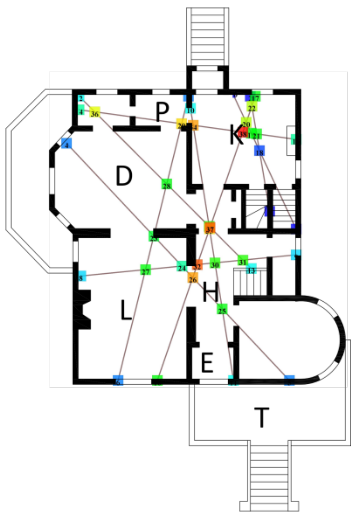
Angular mean depth



Step mean depth



Primal axial map

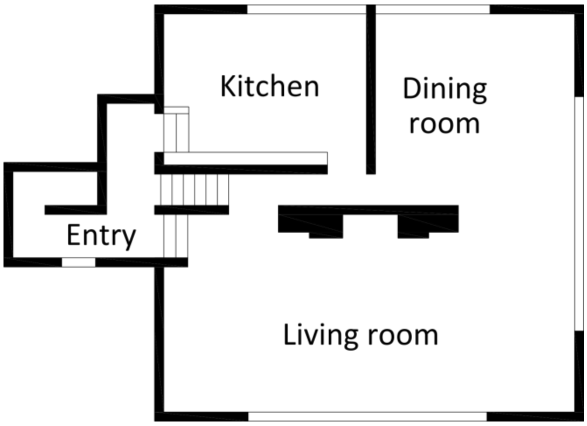


Dual axial map

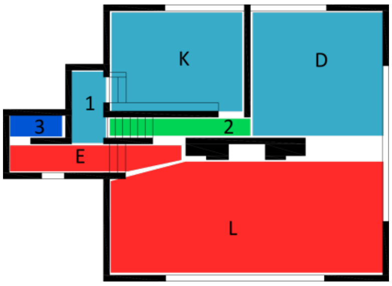
I.2. Prairie houses

1. The "$5000 house plan"

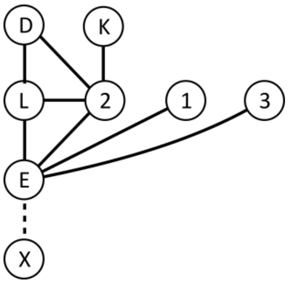
Designed in 1906 as a fireproof house (Futugawa, 1987a, p.246)



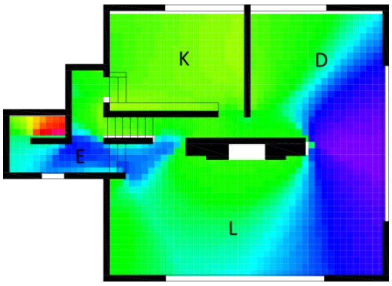
First floor plan



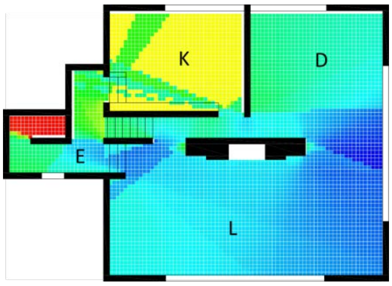
Convex map



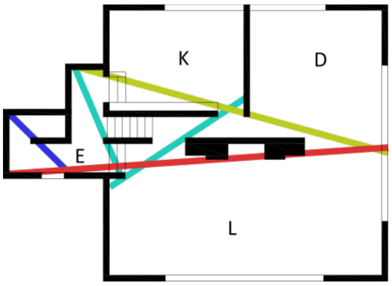
Justified plan graph



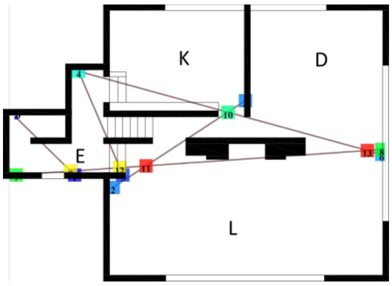
Angular mean depth



Step mean depth



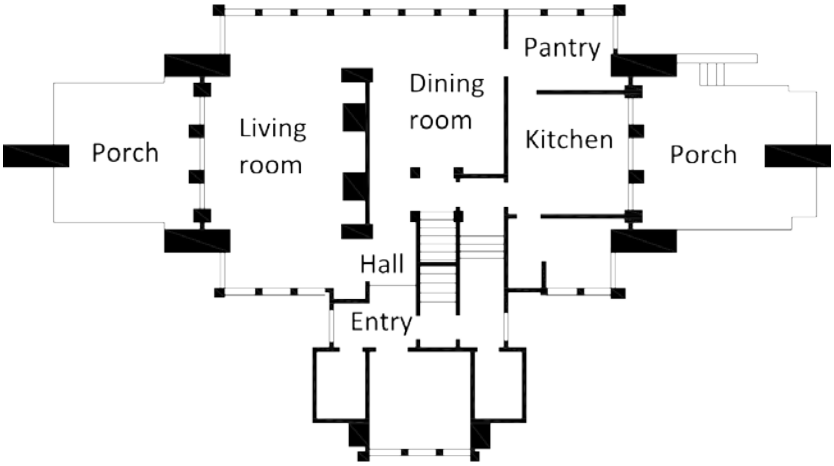
Primal axial map



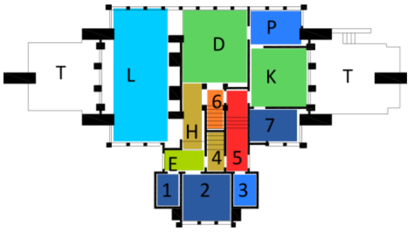
Dual axial map

__2. Adams, House for Mary__

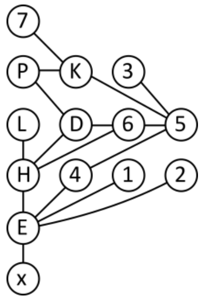
Built in 1905 in Highland Parks, Illinois (Futugawa, 1987a, p. 155)



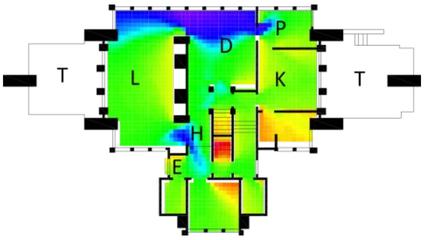
First floor plan



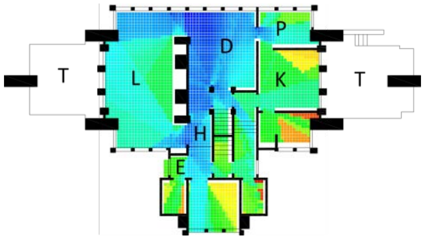
Convex map



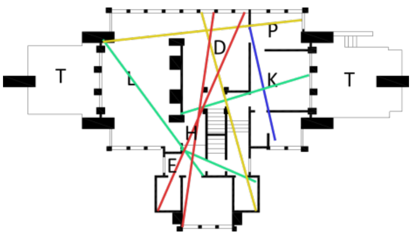
Justified plan graph



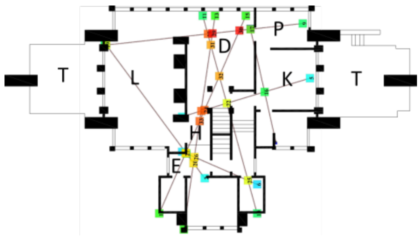
Angular mean depth



Step mean depth



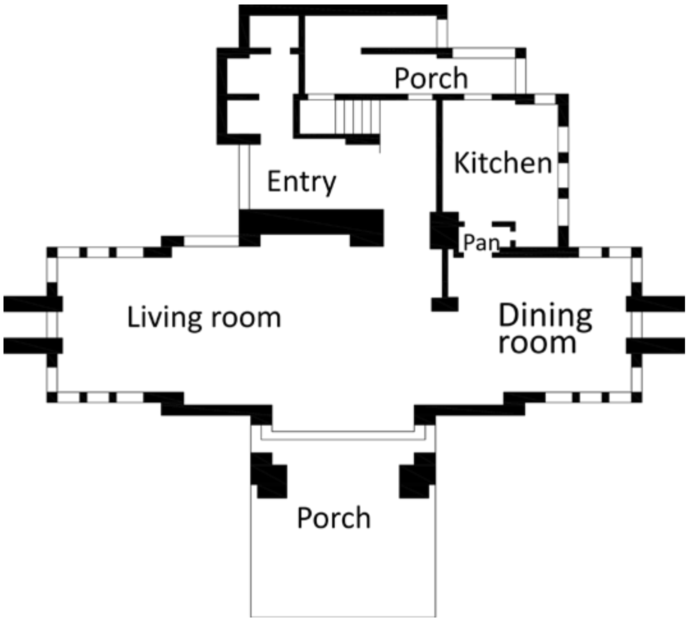
Primal axial map



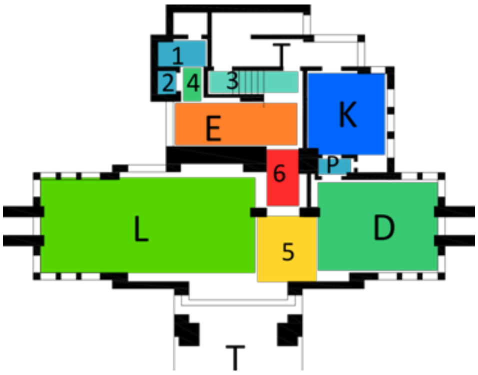
Dual axial map

3. Adams, House for Harry,

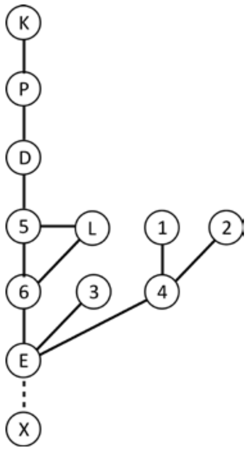
First scheme designed in 1912, Oak Park, Illinois (Futugawa, 1987b, p.197).



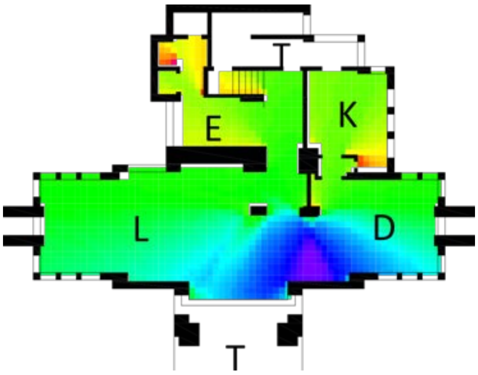
First floor plan



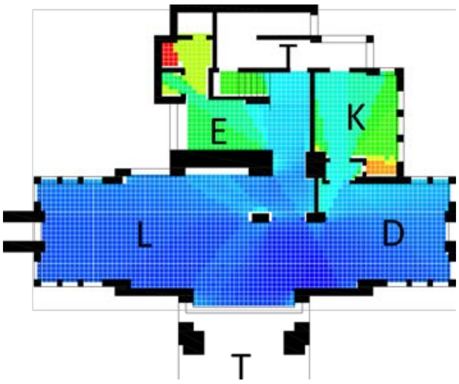
Convex map



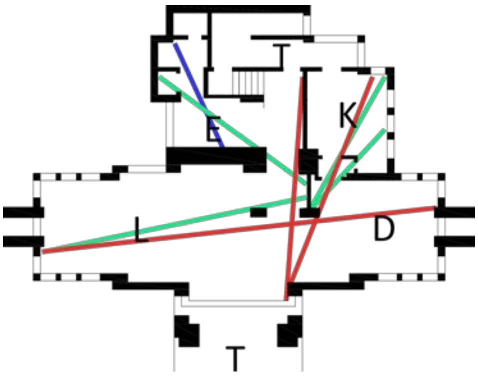
Justified plan graph



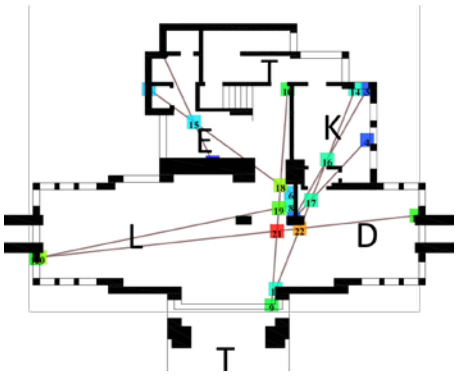
Angular mean depth



Step mean depth



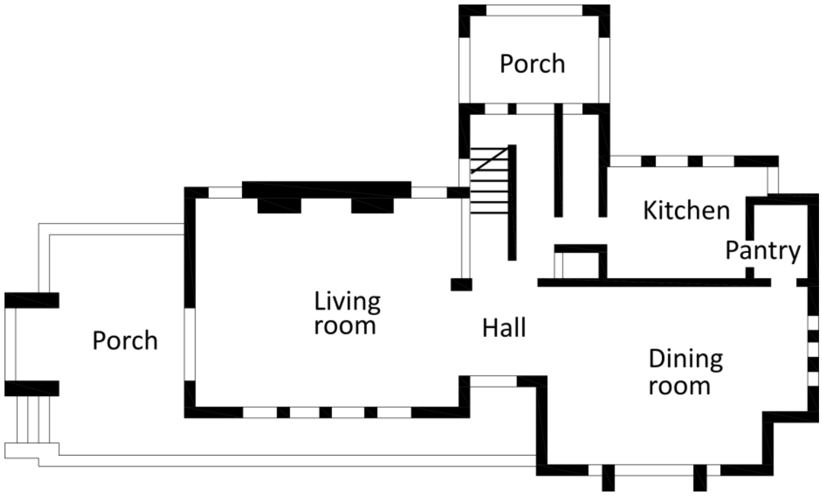
Primal axial map



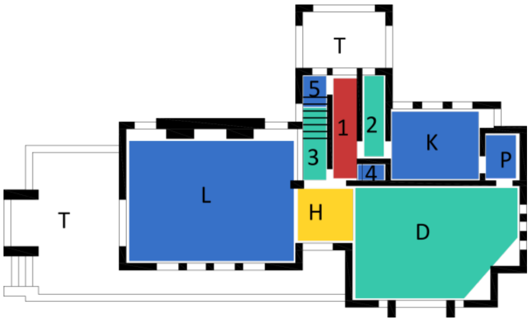
Dual axial map

4. Adams, house for Harry (#2)

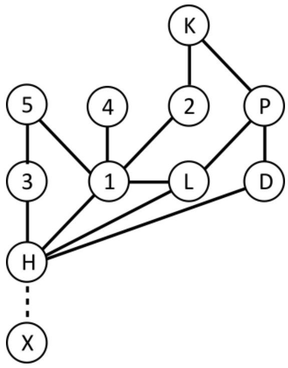
Second scheme designed in 1913, Oak Park Illinois (Futugawa, 1987b, p. 202)



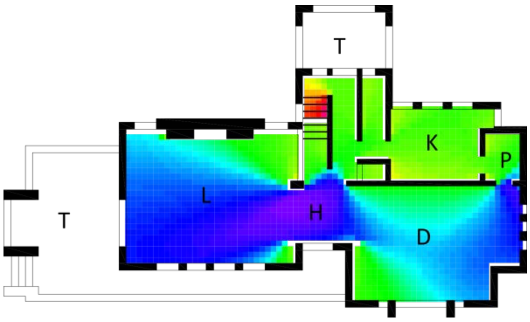
First floor plan



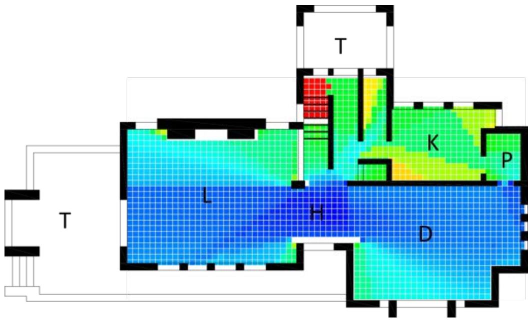
Convex map



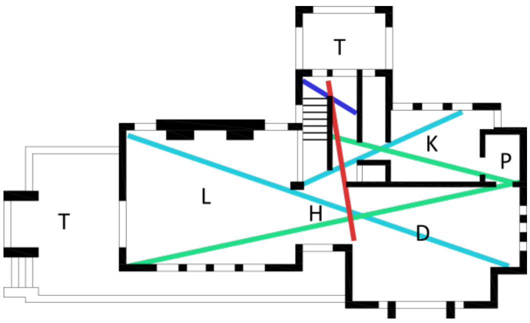
Justified plan graph



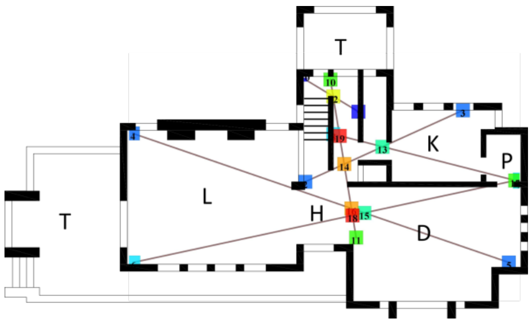
Angular mean depth



Step mean depth



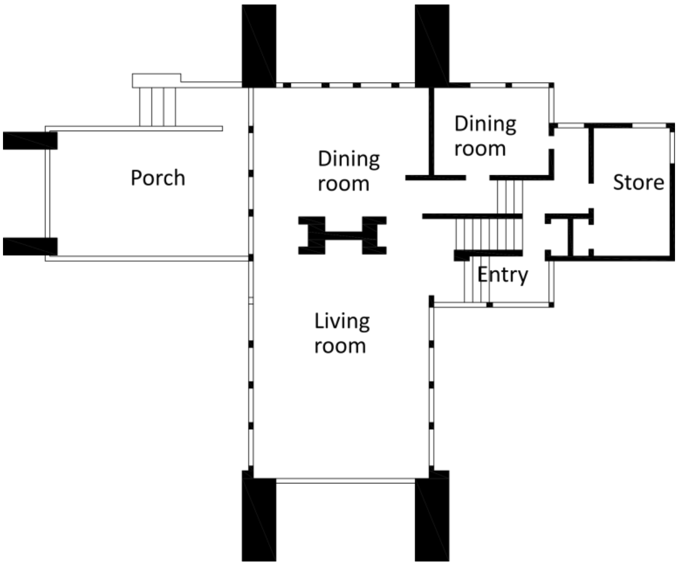
Primal axial map



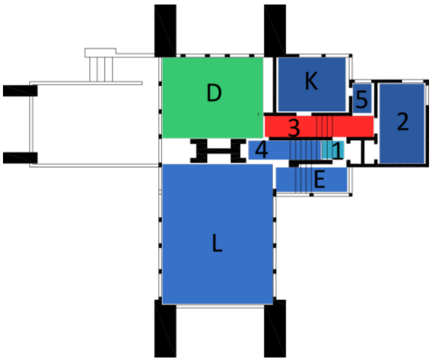
Dual axial map

5. Baker, house for Frank,

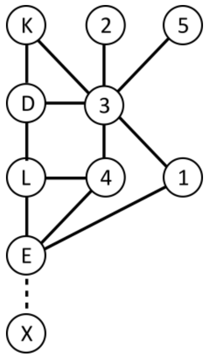
Scheme designed in 1909 in Wilmette, Illinois (Futugawa, 1987b, p. 76).



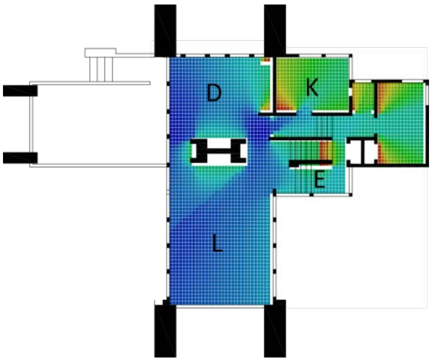
First floor plan



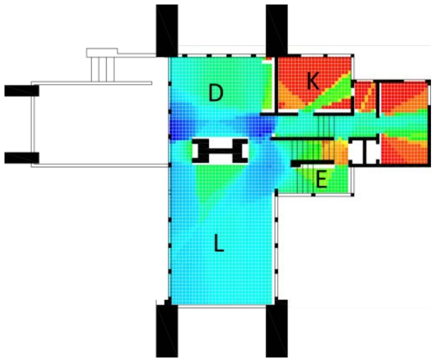
Convex map



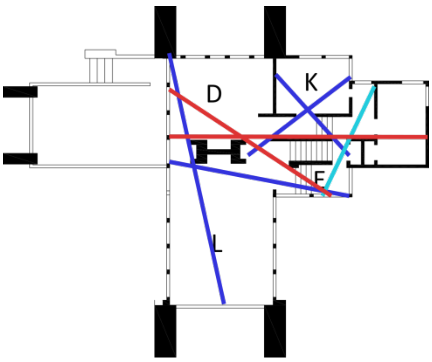
Justified plan graph



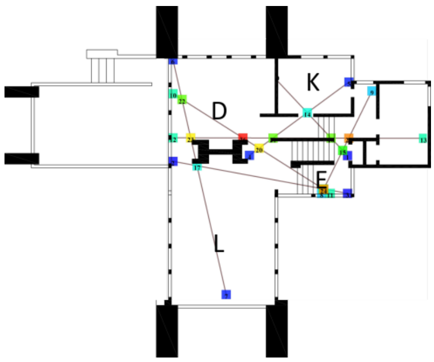
Angular mean depth



Step mean depth



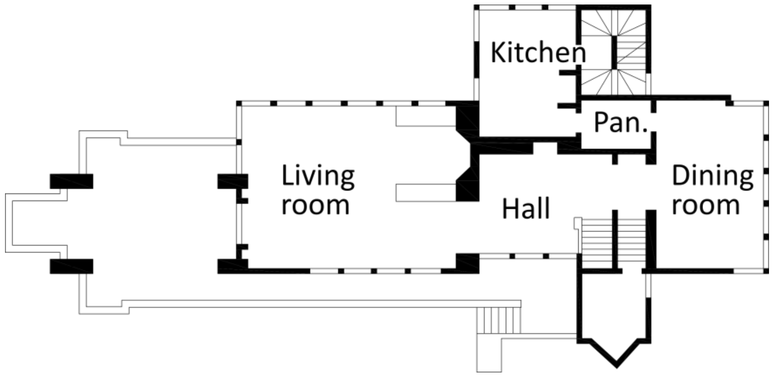
Primal axial map



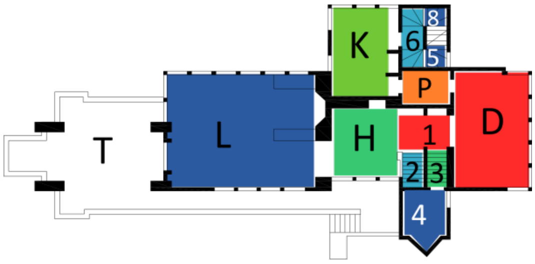
Dual axial map

6. Baldwin, house for Hiram

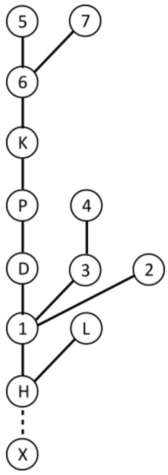
Scheme #1 in 1904, in Kenilworth, Illinois (Futugawa, 1987a, p. 158).



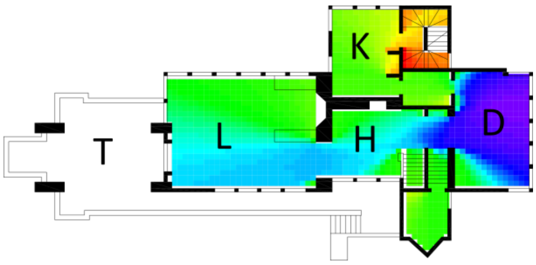
First floor plan



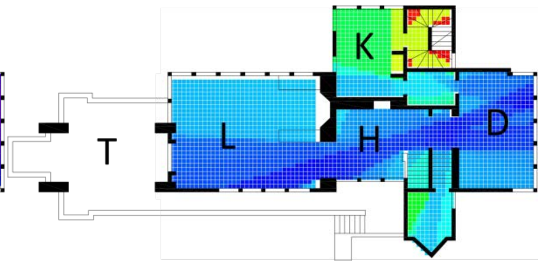
Convex map



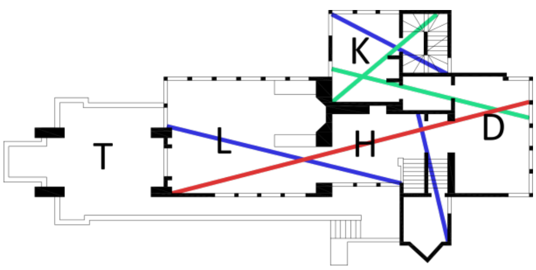
Justified plan graph



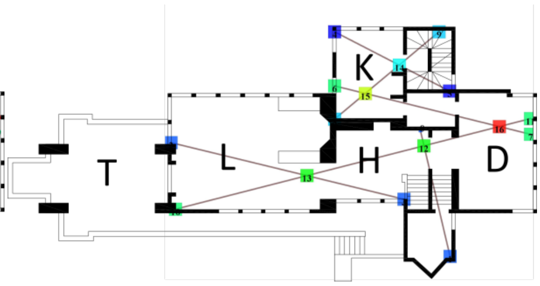
Angular mean depth



Step mean depth



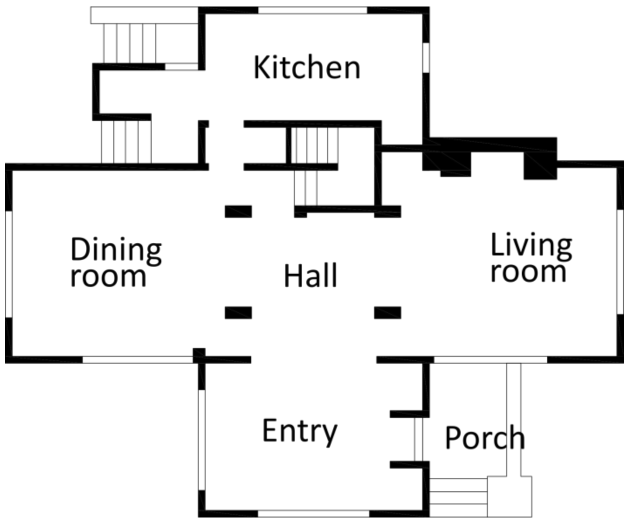
Primal axial map



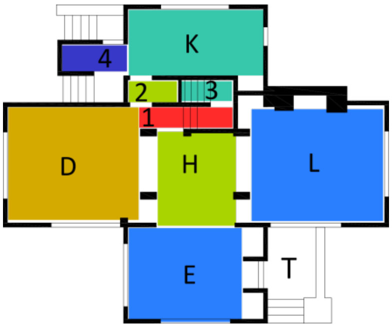
Dual axial map

7. Barnes, house for Charles

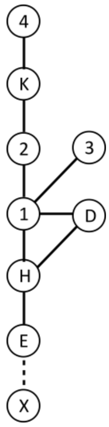
Scheme in 1904 in McCook, Nebraska (Futugawa, 1987a, p. 126)



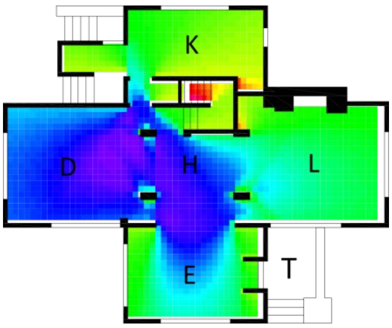
First floor plan



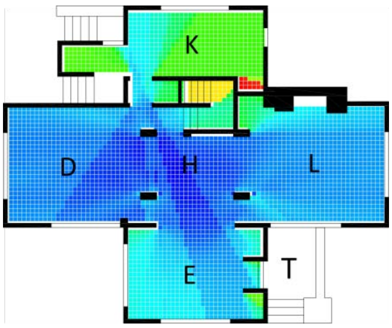
Convex map



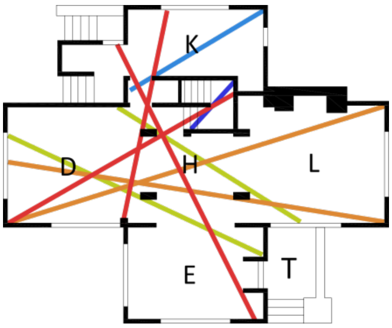
Justified plan graph



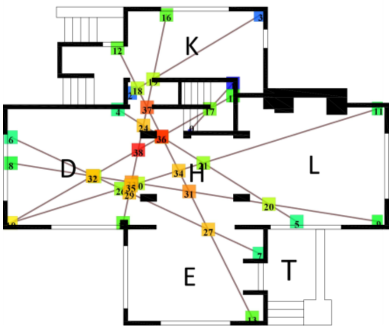
Angular mean depth



Step mean depth



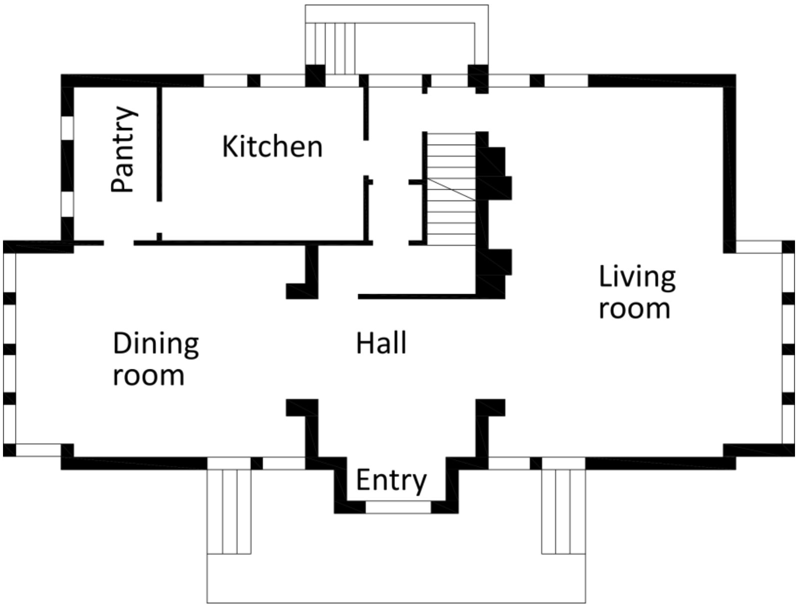
Primal axial map



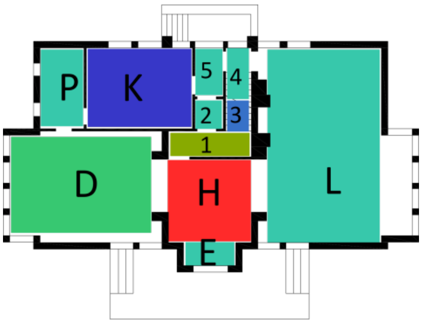
Dual axial map

8. Brown, house for Harry

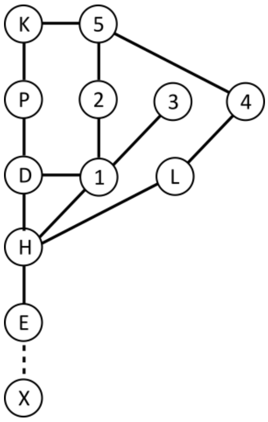
Second scheme in 1906, in Genesco, Illinois (Futugawa, 1987a, p. 167)



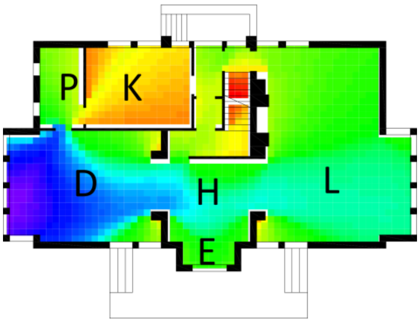
First floor plan



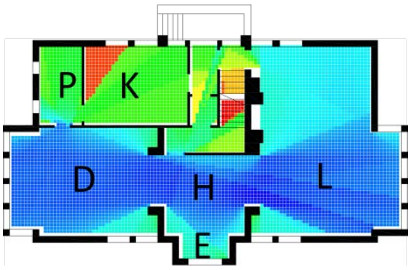
Convex map



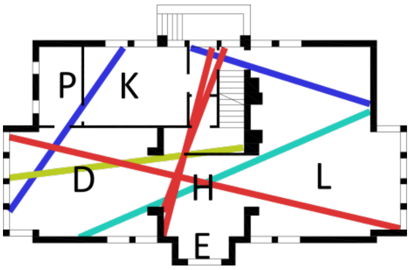
Justified plan graph



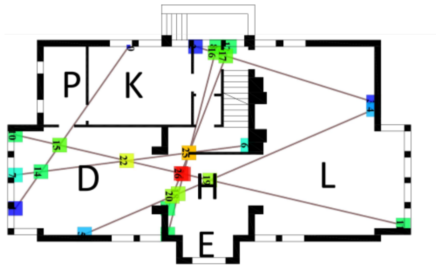
Angular mean depth



Step mean depth



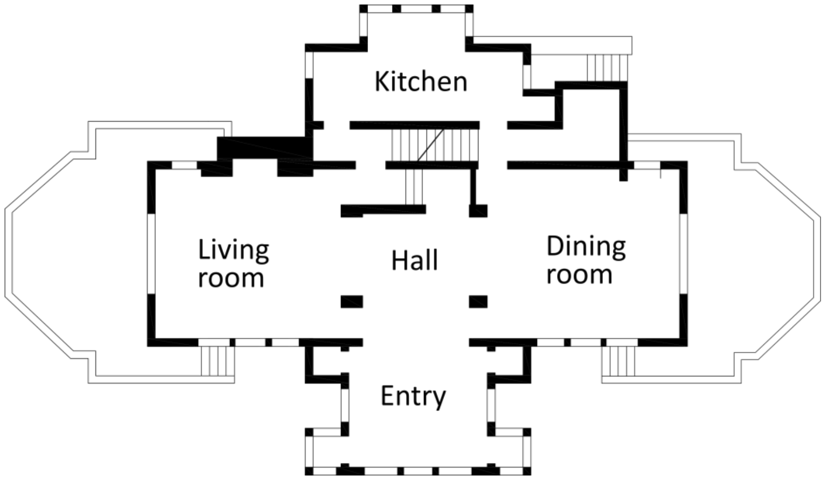
Primal axial map



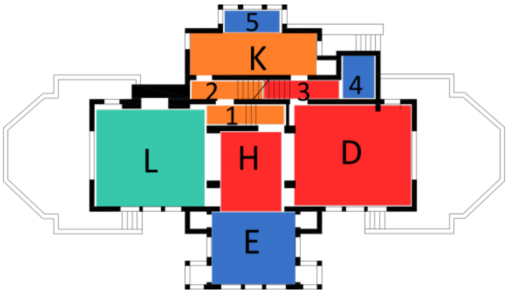
Dual axial map

9. DeRhodes, house for K.C,

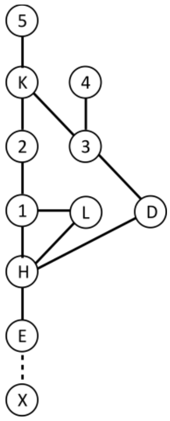
Built in 1906 in South Bend, Indiana (Futugawa, 1987a, p. 217).



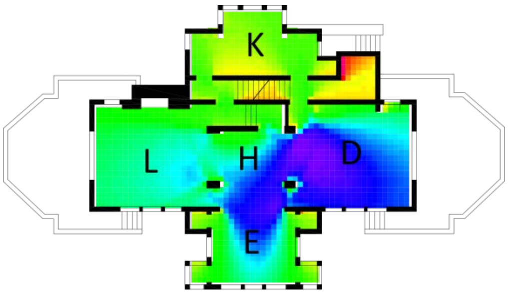
First floor plan



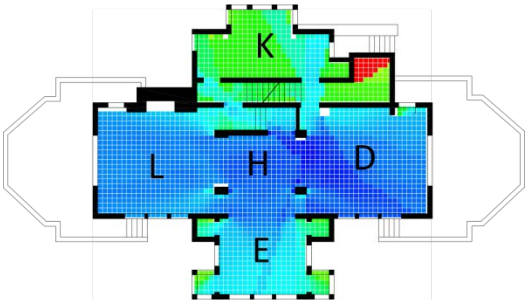
Convex map



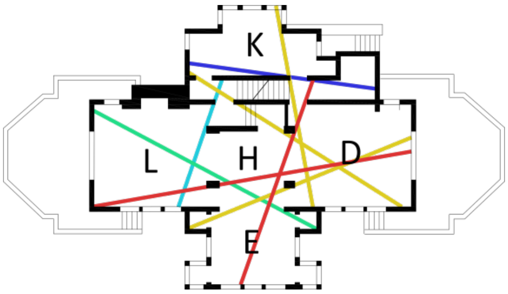
Justified plan graph



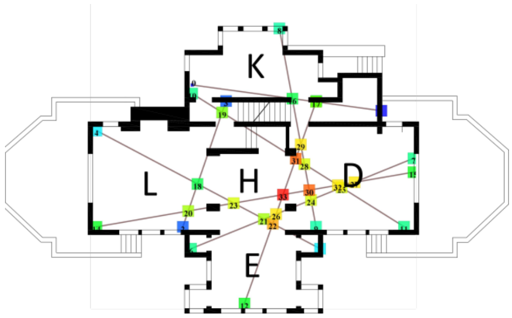
Angular mean depth



Step mean depth



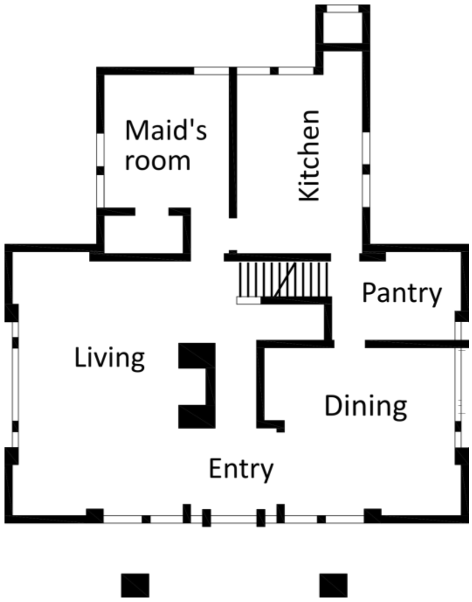
Primal axial map



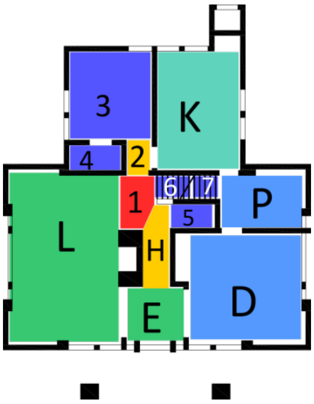
Dual axial map

10. Fuller, house for Grace,

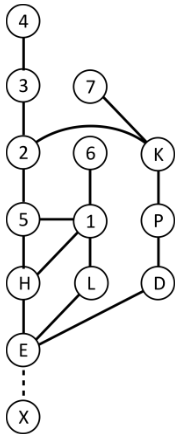
Built in 1906, in Glencoe, Illinois (Futugawa, 1987a, p. 225).



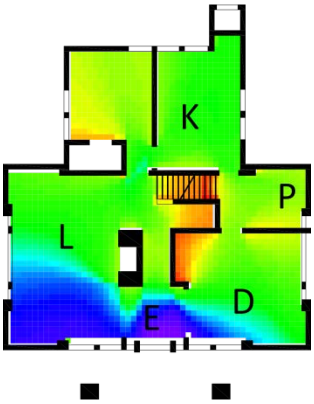
First floor plan



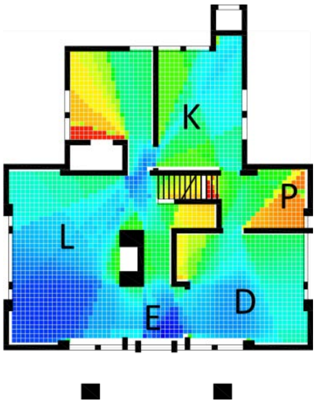
Convex map



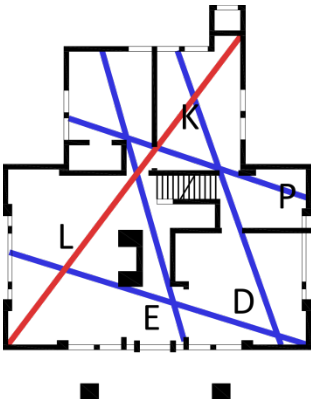
Justified plan graph



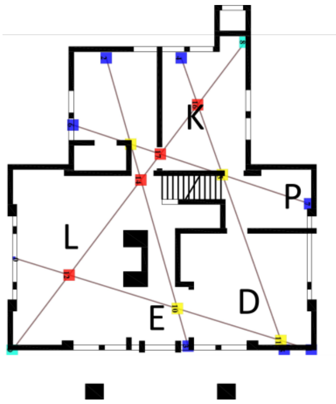
Angular mean depth



Step mean depth



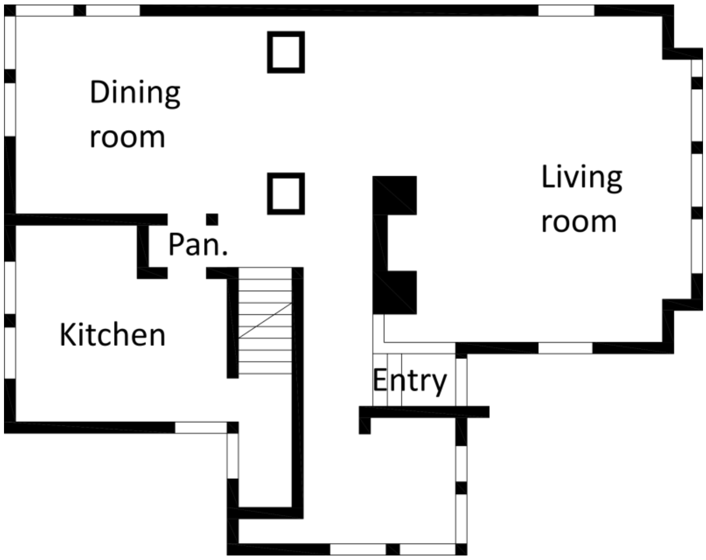
Primal axial map



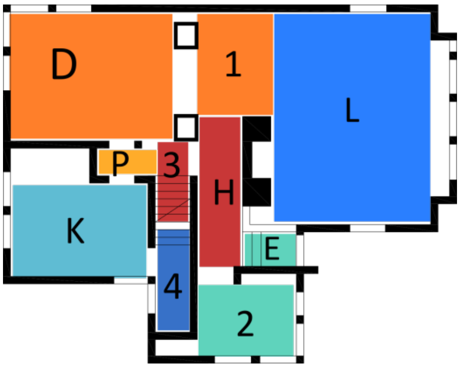
Dual axial map

11. Gale, house for Mrs.. Thomas,

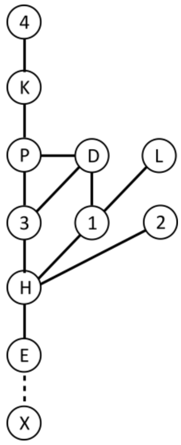
Built in 1909, Oak Park, Illinois (Futugawa, 1987b, p. 109).



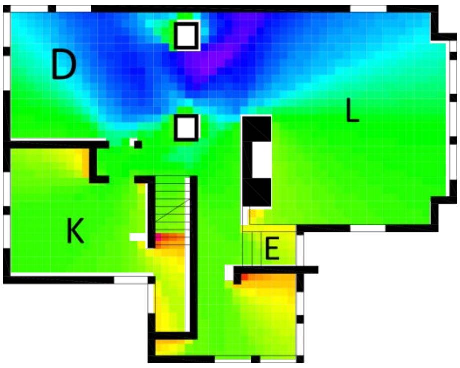
First floor plan



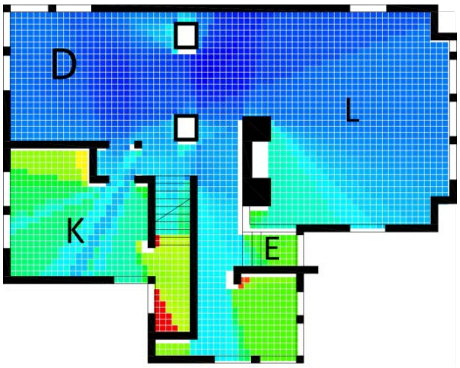
Convex map



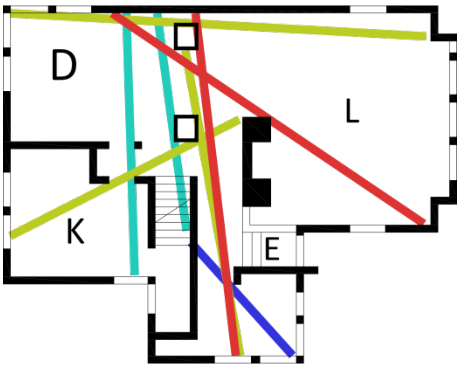
Justified plan graph



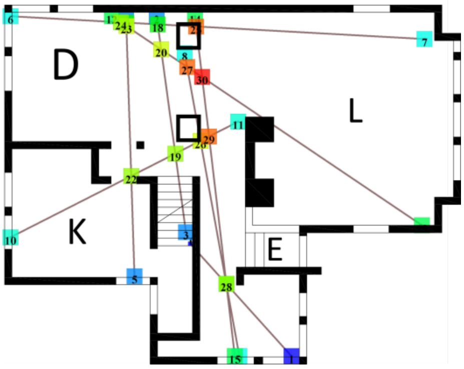
Angular mean depth



Step mean depth



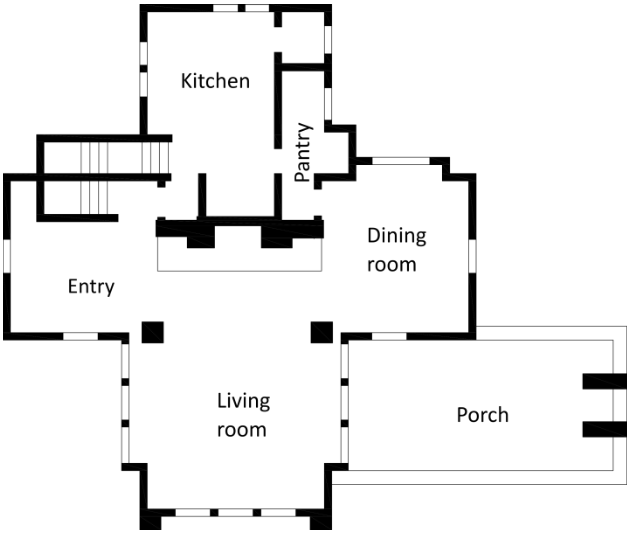
Primal axial map



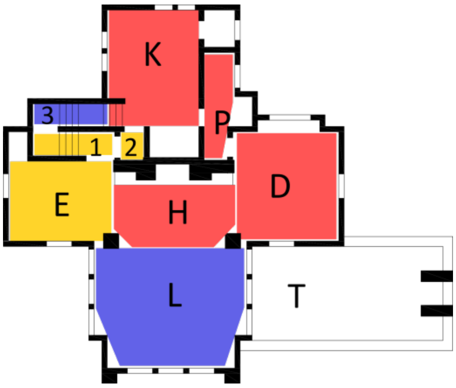
Dual axial map

12. Kellogg, house for J.W.,

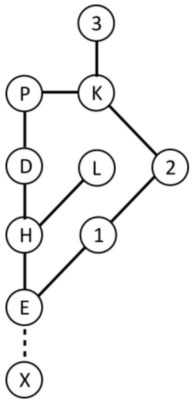
Scheme in 1913, Milwaukie, Wisconsin (Futugawa, 1987b, p. 234).



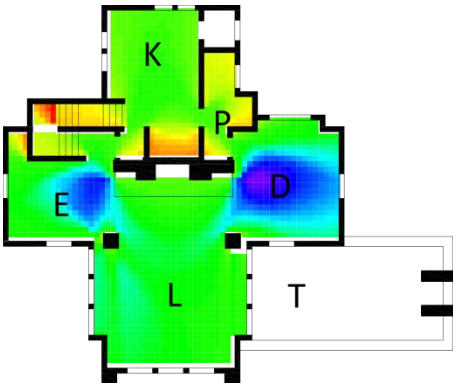
First floor plan



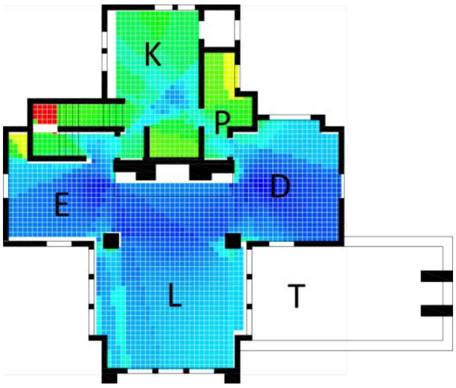
Convex map



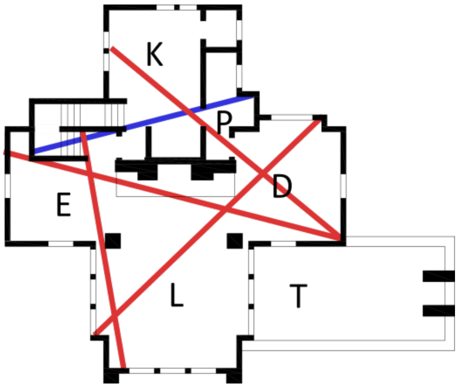
Justified plan graph



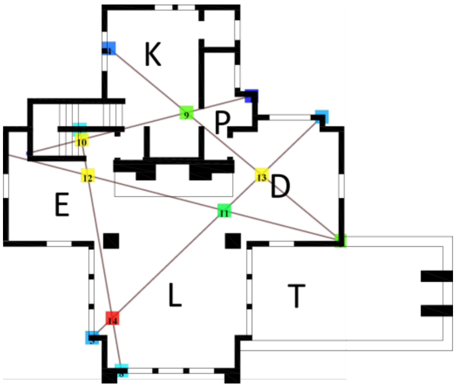
Angular mean depth



Step mean depth



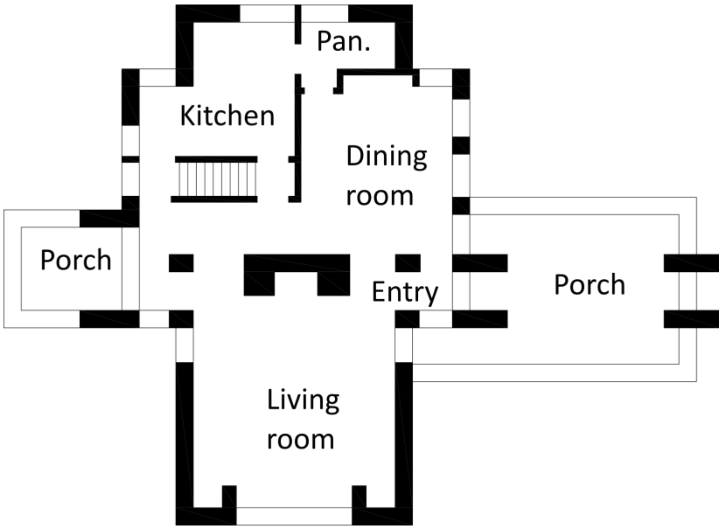
Primal axial map



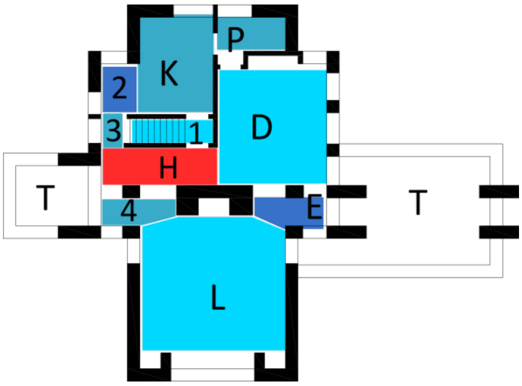
Dual axial map

13. Larwill, house for

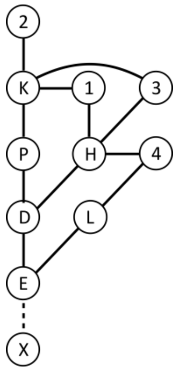
Scheme in 1909, in Muskegon, Michigan (Futugawa, 1987b, p.101).



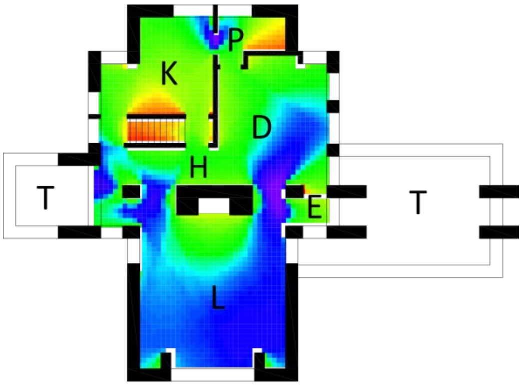
First floor plan



Convex map

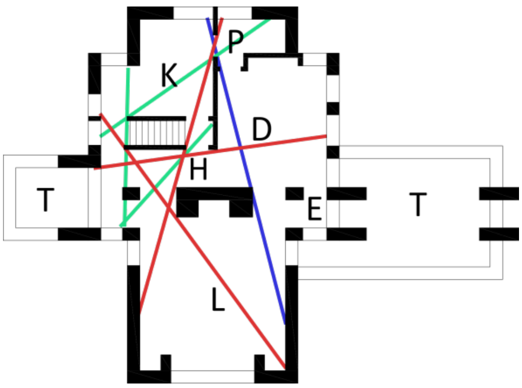


Justified plan graph

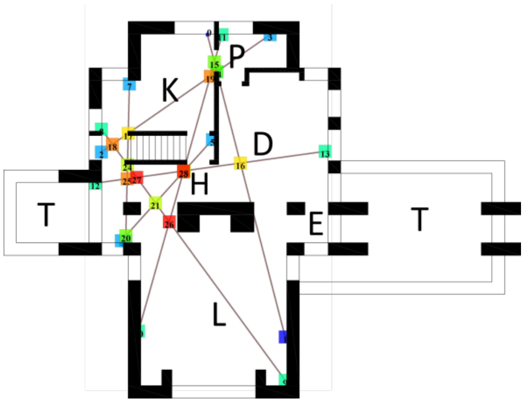


Angular mean depth

Step mean depth



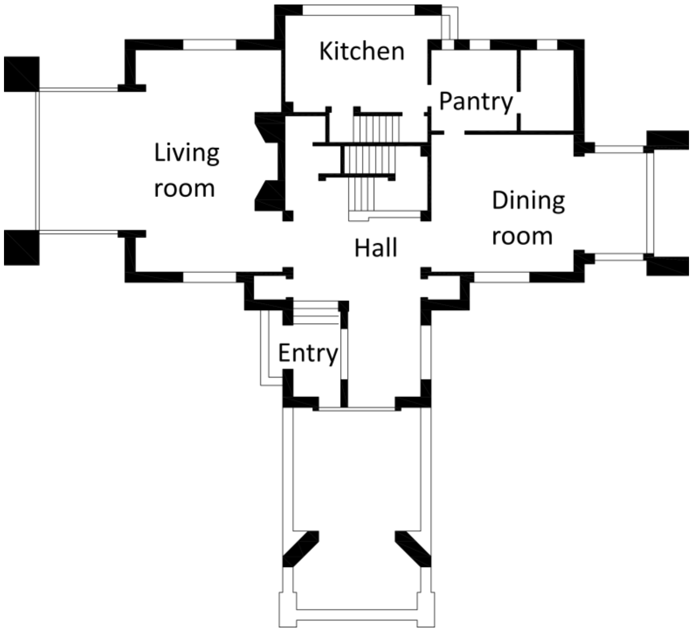
Primal axial map



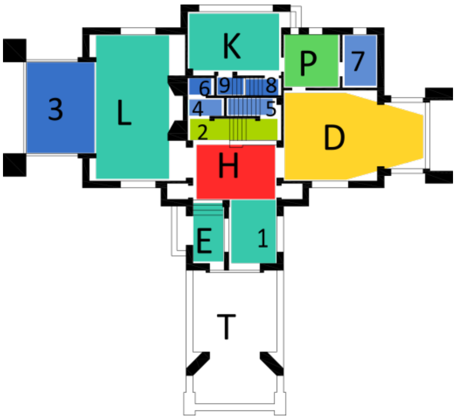
Dual axial map

14. Little, house for Francis W.,

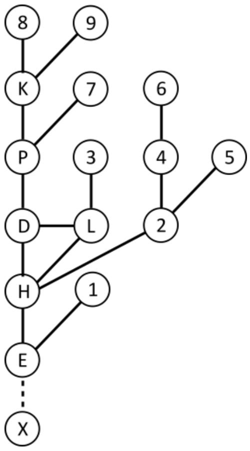
Built in 1902, in Peoria, Illinois (Futugawa, 1987a, p. 16).



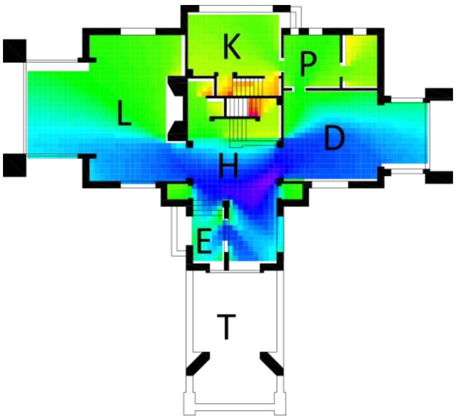
First floor plan



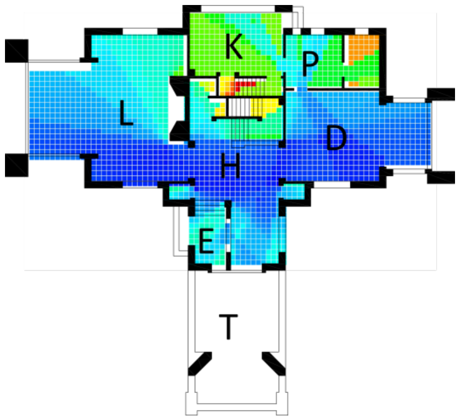
Convex map



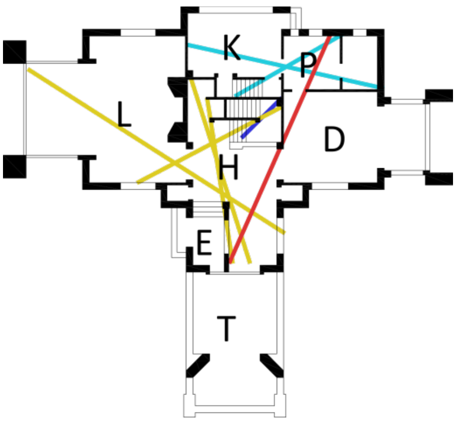
Justified plan graph



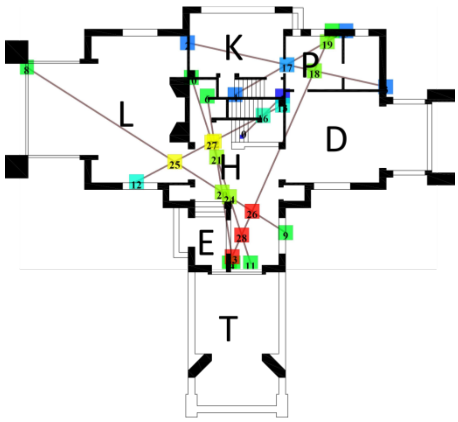
Angular mean depth



Step mean depth



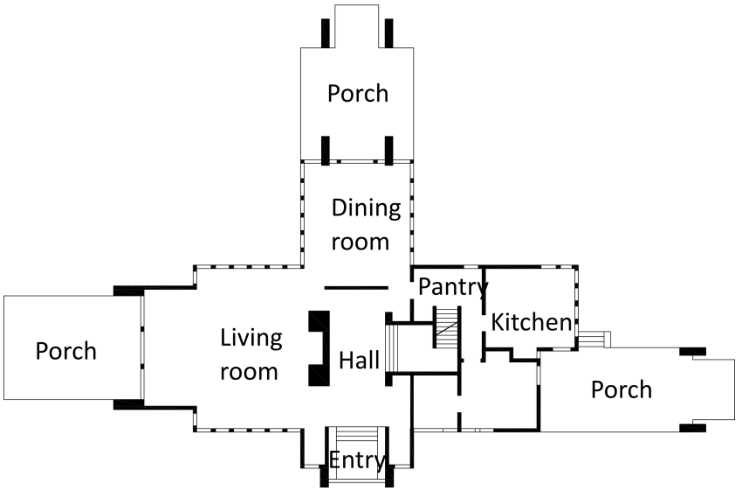
Primal axial map



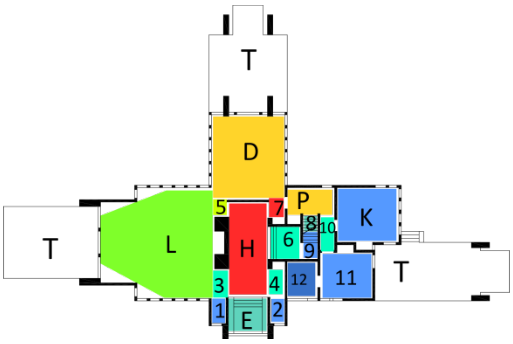
Dual axial map

15. Little, house for Francis W.,

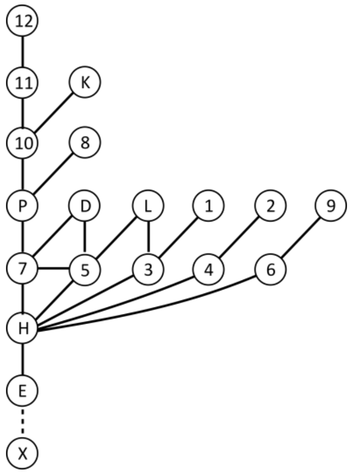
Scheme for summerhouse in 1908, Wayzata, Minnesota (Futugawa, 1987b, p. 86)



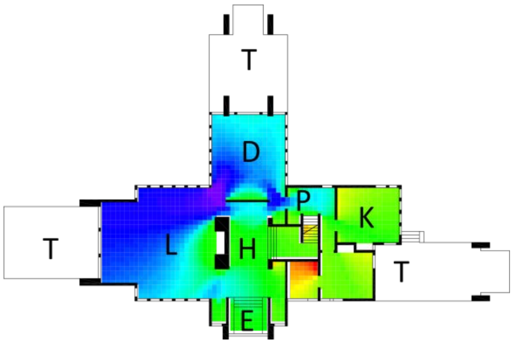
First floor plan



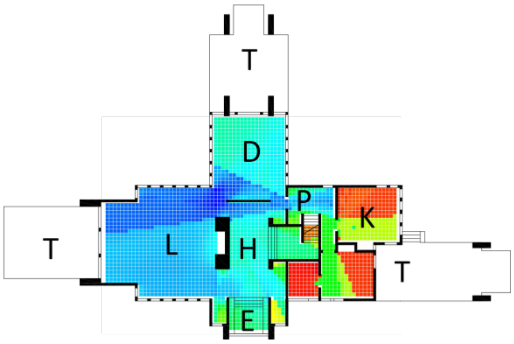
Convex map



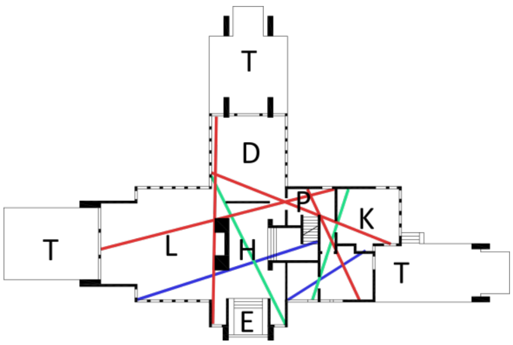
Justified plan graph



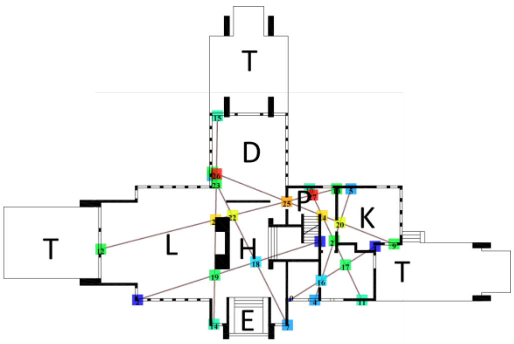
Angular mean depth



Step mean depth



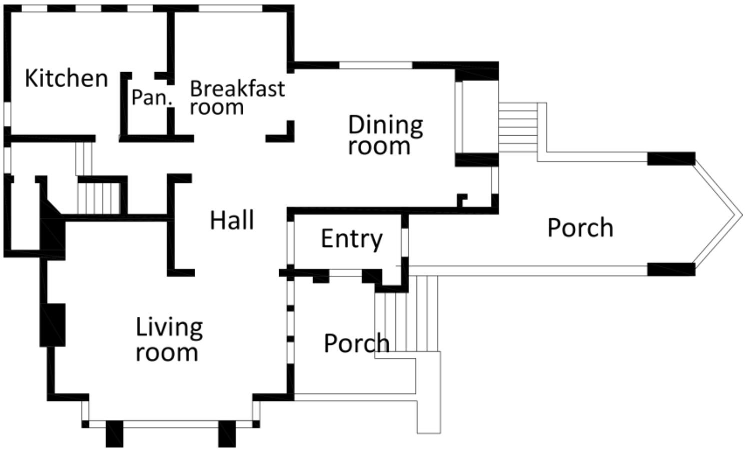
Primal axial map



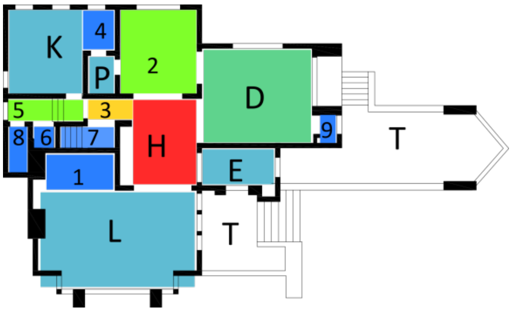
Dual axial map

16. Martin, house for William E.,

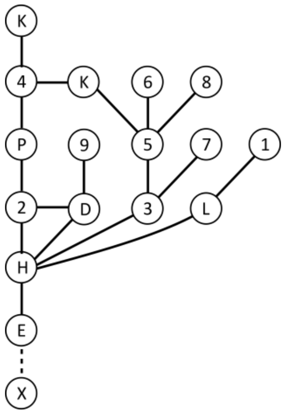
Built in 1902, Oak Park, Illinois (Futugawa, 1987a, p. 8).



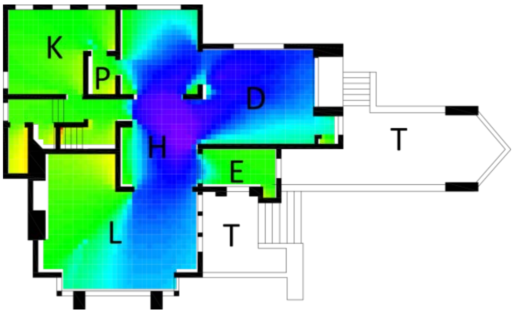
First floor plan



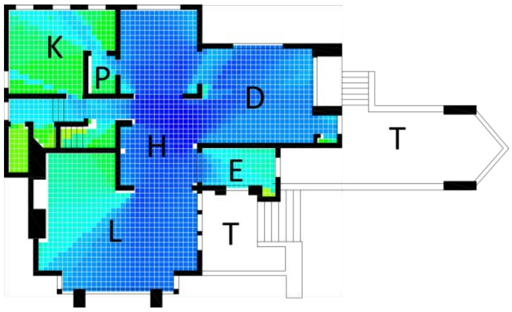
Convex map



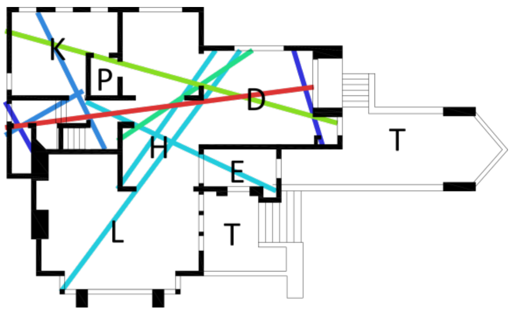
Justified plan graph



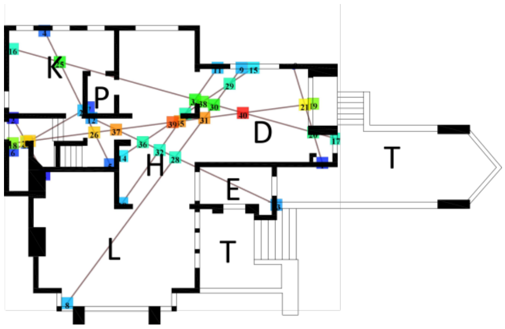
Angular mean depth



Step mean depth



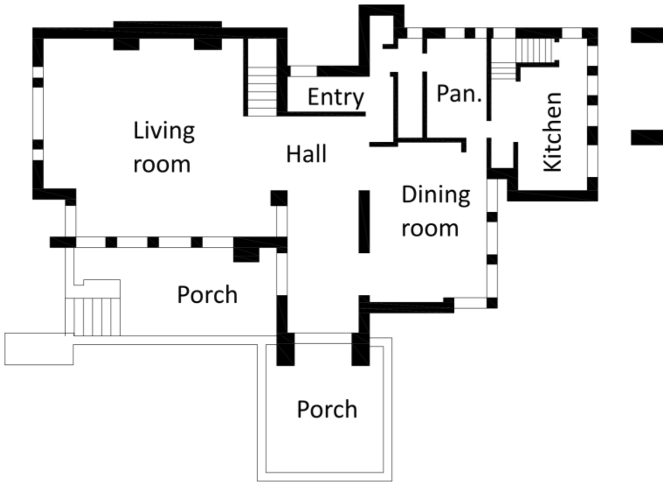
Primal axial map



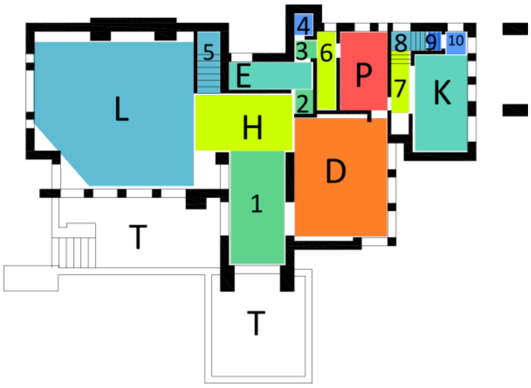
Dual axial map

17. May, house for Meyer,

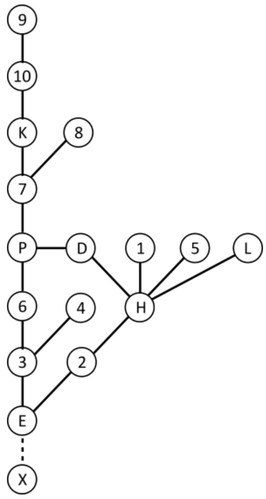
Built in 1908, Grand Rapids, Michigan (Futugawa, 1987b, p. 72).



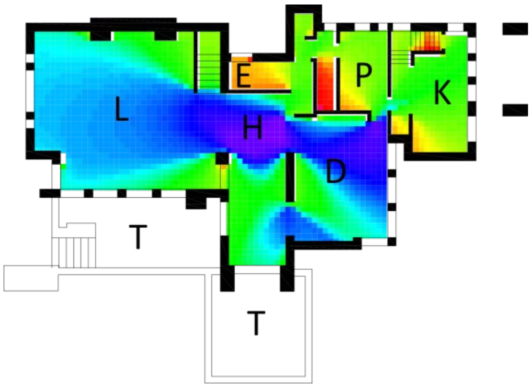
First floor plan



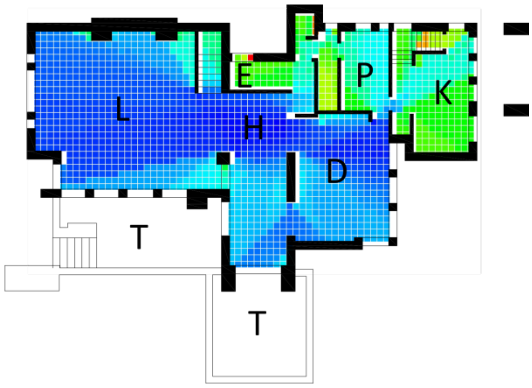
Convex map



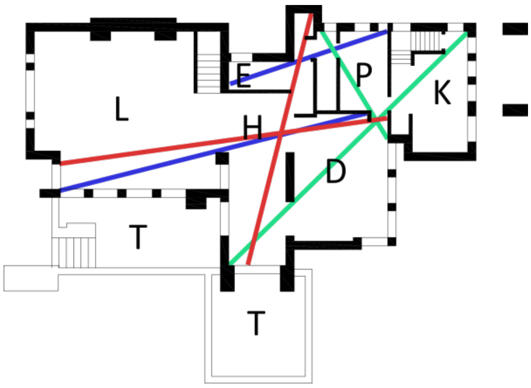
Justified plan graph



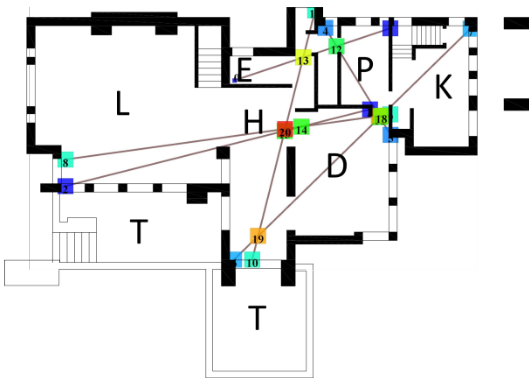
Angular mean depth



Step mean depth



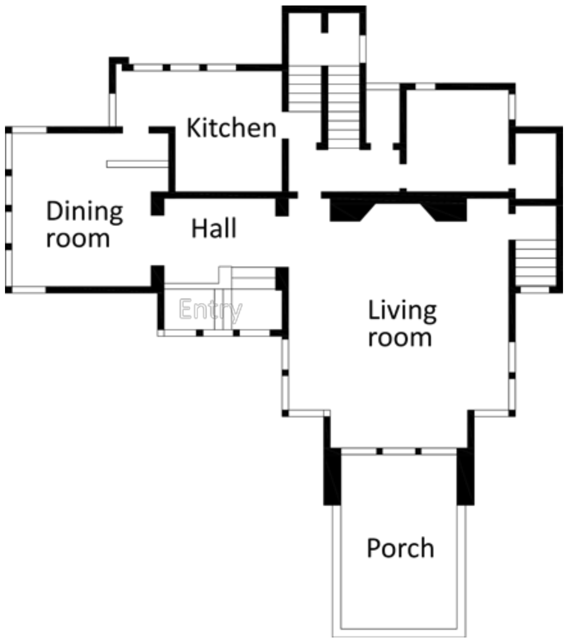
Primal axial map



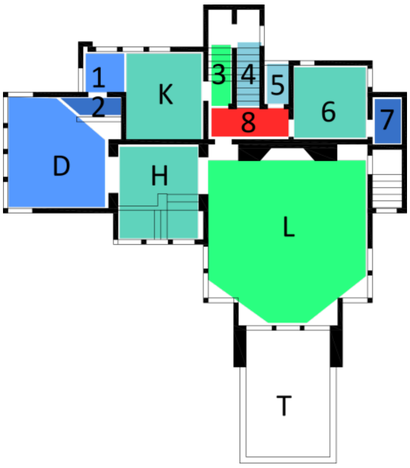
Dual axial map

18. Millard, house for George Madison,

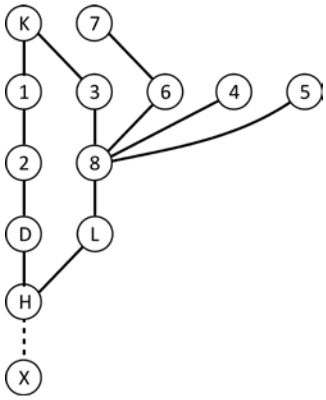
Built in 1906, Highland Park, Illinois (Futugawa, 1987a, p. 234).



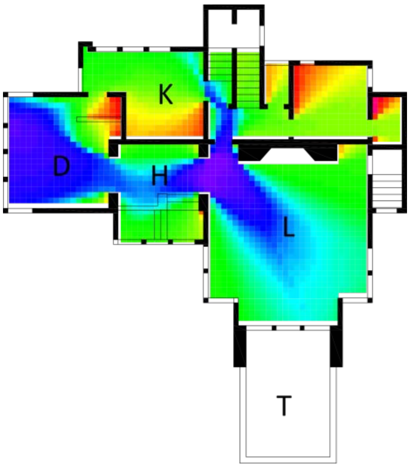
First floor plan



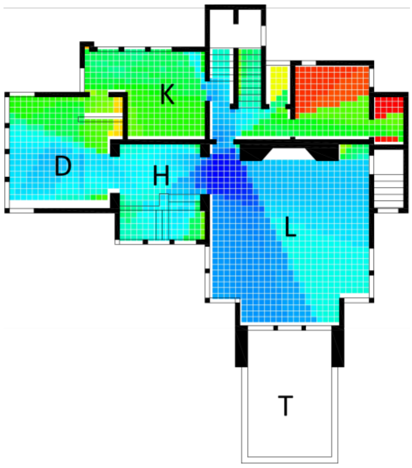
Convex map



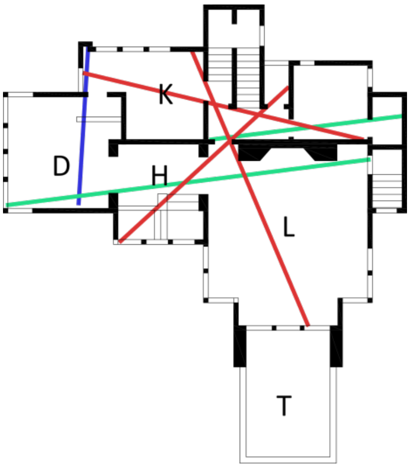
Justified plan graph



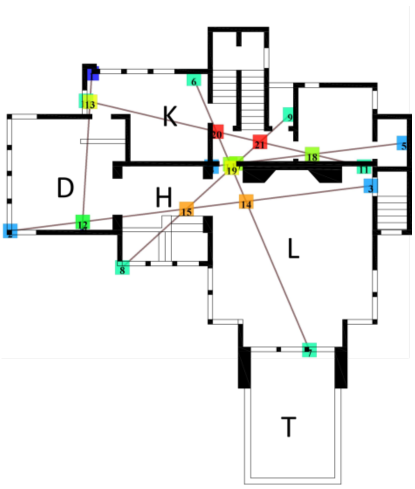
Angular mean depth



Step mean depth



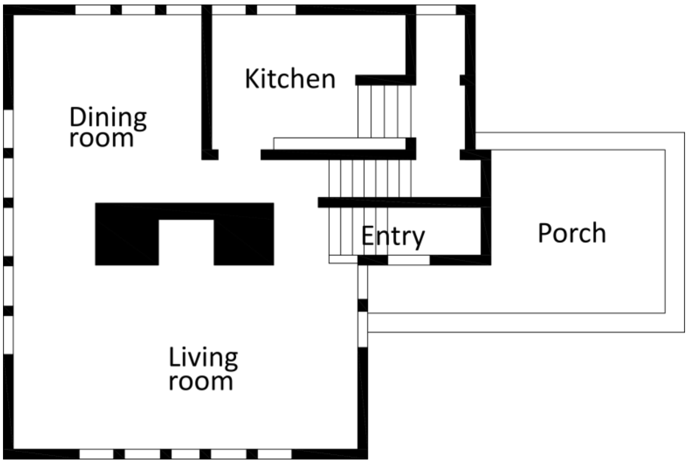
Primal axial map



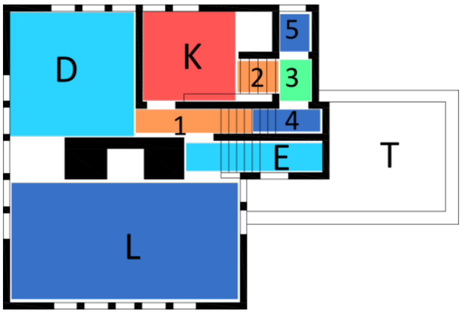
Dual axial map

19. Nicholas, house for Frederick,

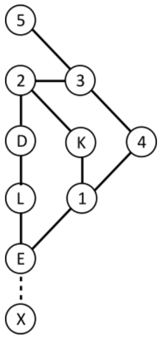
Built in 1906, Flossmoor, Illinois (Futugawa, 1987a, p. 217).



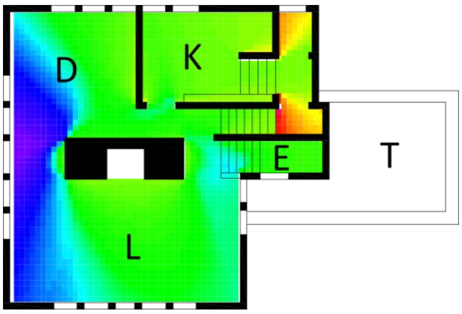
First floor plan



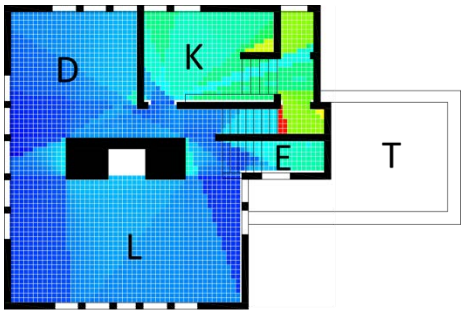
Convex map



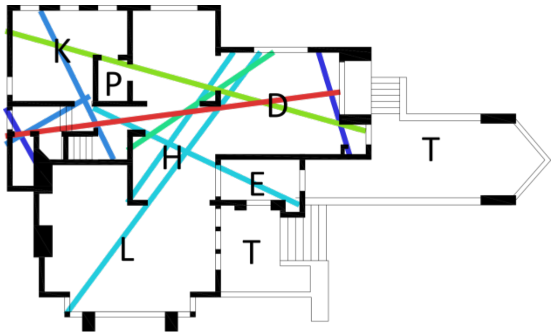
Justified plan graph



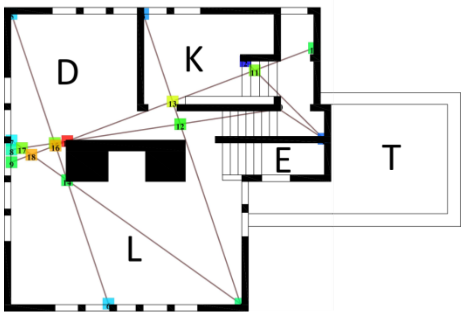
Angular mean depth



Step mean depth



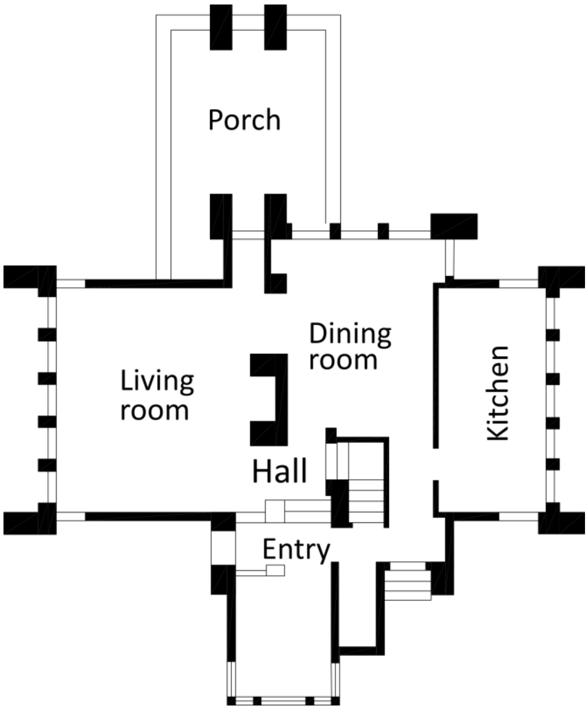
Primal axial map



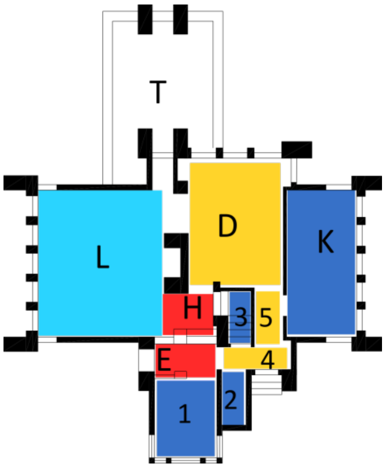
Dual axial map

20. Robert, house for Charles E.,

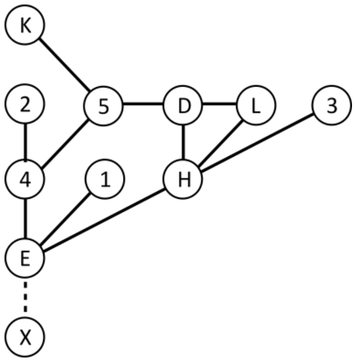
Built in 1902 in Oak Park, Illinois (Futugawa, 1987a, p. 64).



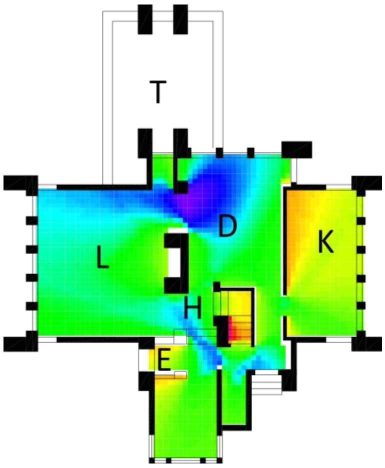
First floor plan



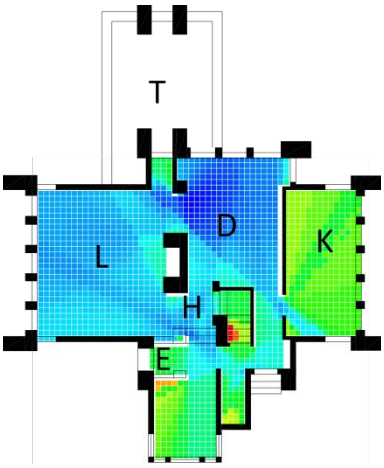
Convex map



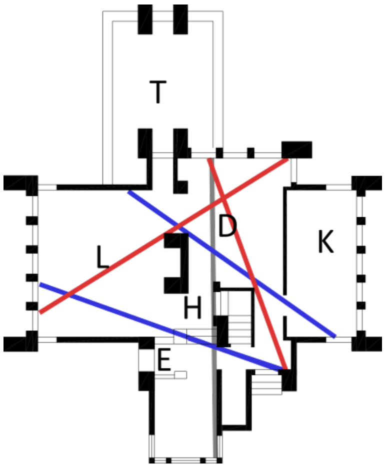
Justified plan graph



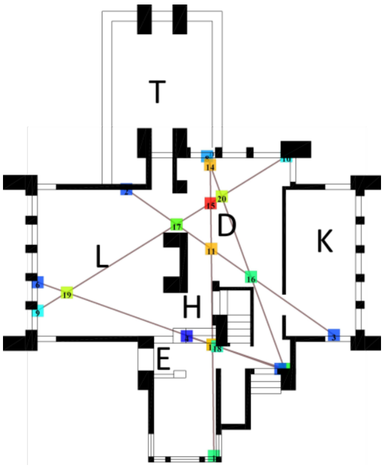
Angular mean depth



Step mean depth



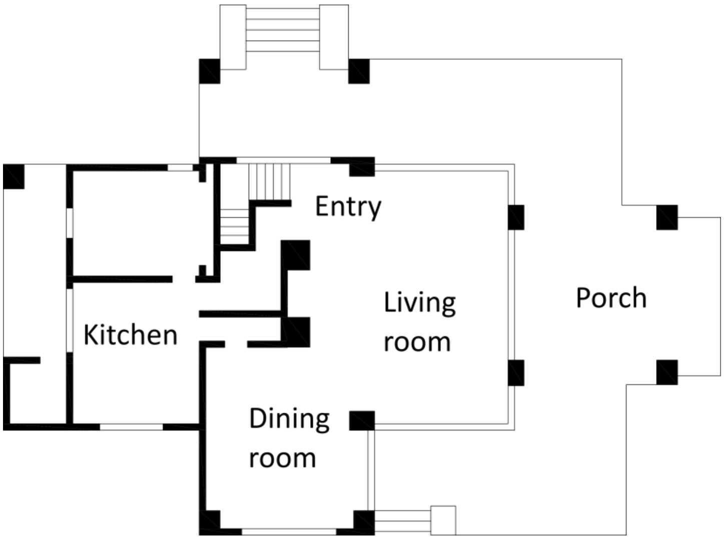
Primal axial map



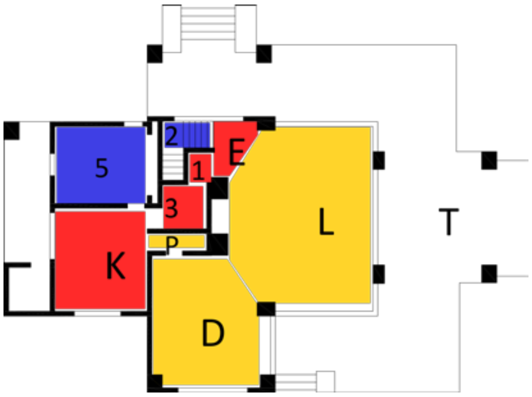
Dual axial map

21. Ross, house for Charles,

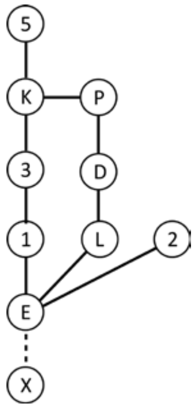
Built in 1902 in Lake Delavan, Wisconsin (Futugawa, 1987a, p. 39).



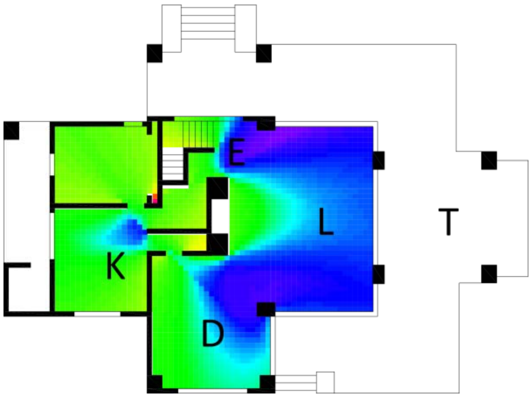
First floor plan



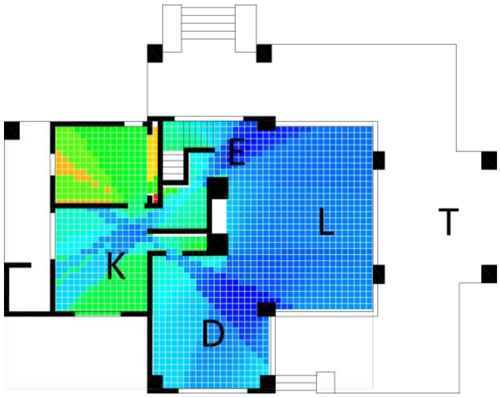
Convex map



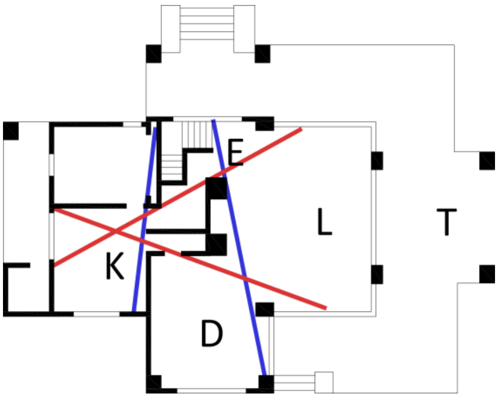
Justified plan graph



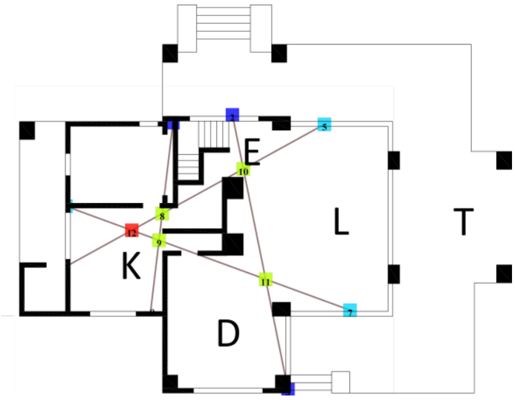
Angular mean depth



Step mean depth



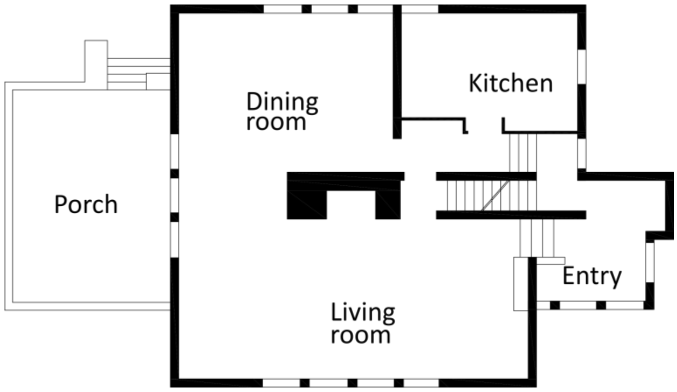
Primal axial map



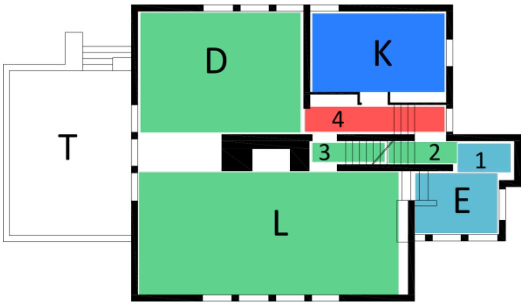
Dual axial map

22. Stockman, house for Dr. G.C.,

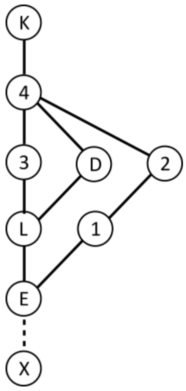
Built in 1908 in Mason City, Iowa (Futugawa, 1987b, p. 70)



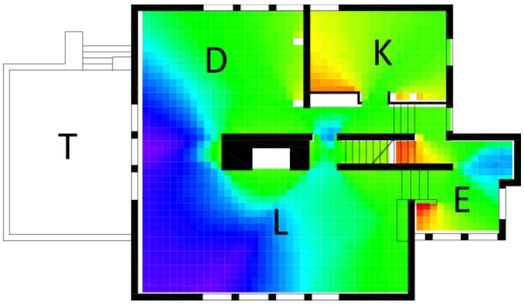
First floor plan



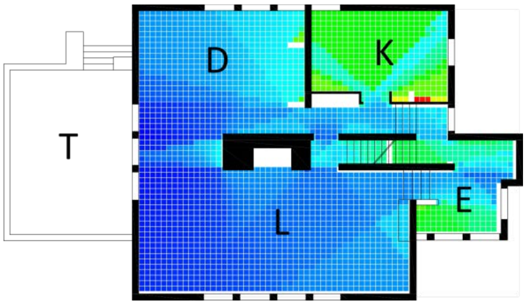
Convex map



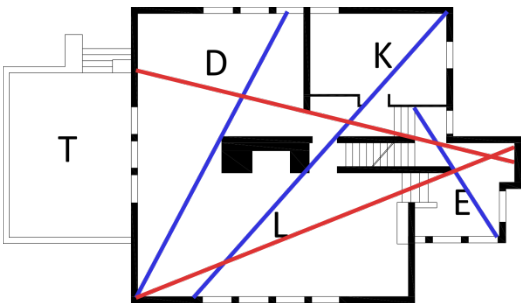
Justified plan graph



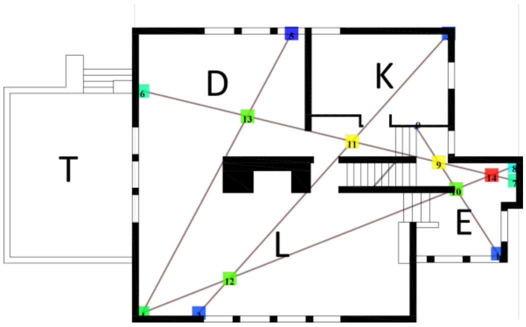
Angular mean depth



Step mean depth



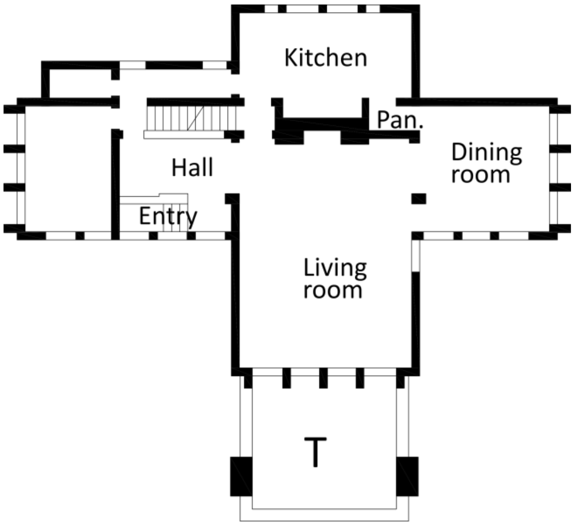
Primal axial map



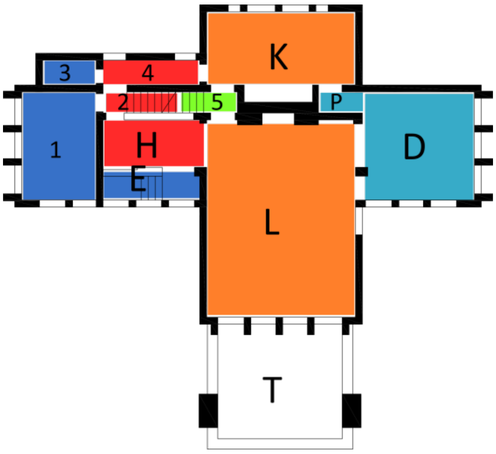
Dual axial map

23. Sutton, house for Harvey,

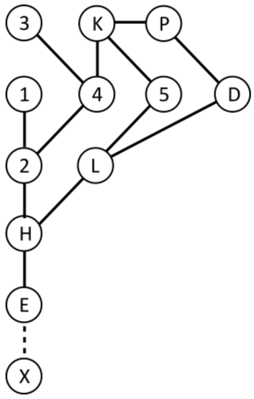
Scheme #1 in 1905 in McCook, Nebraska (Futugawa, 1987a, p. 173).



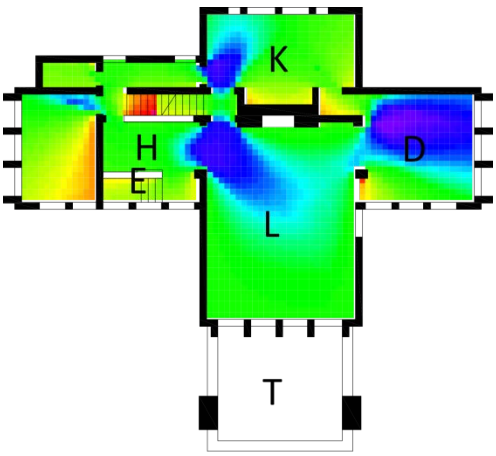
First floor plan



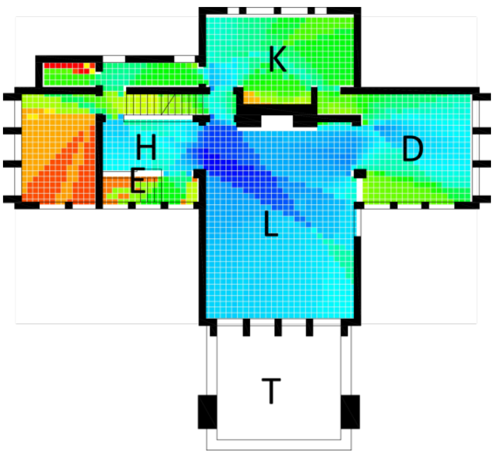
Convex map



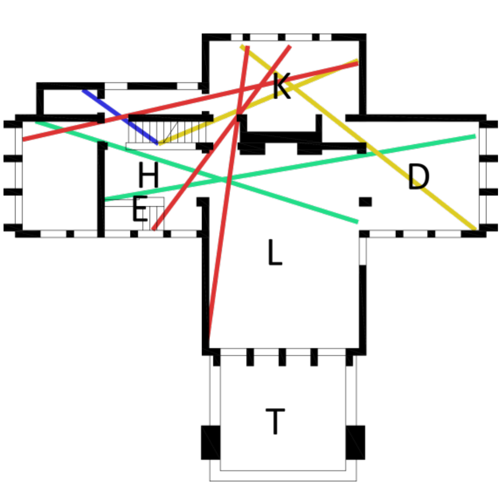
Justified plan graph



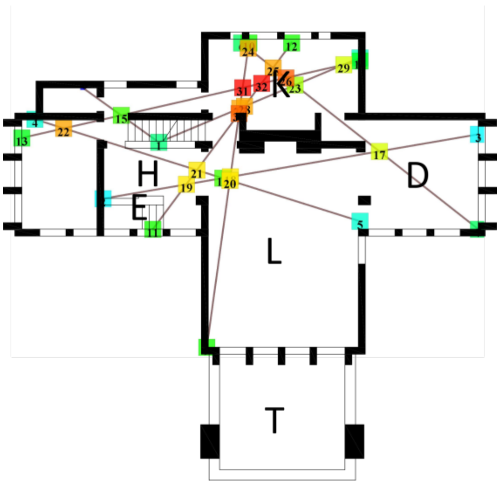
Angular mean depth



Step mean depth



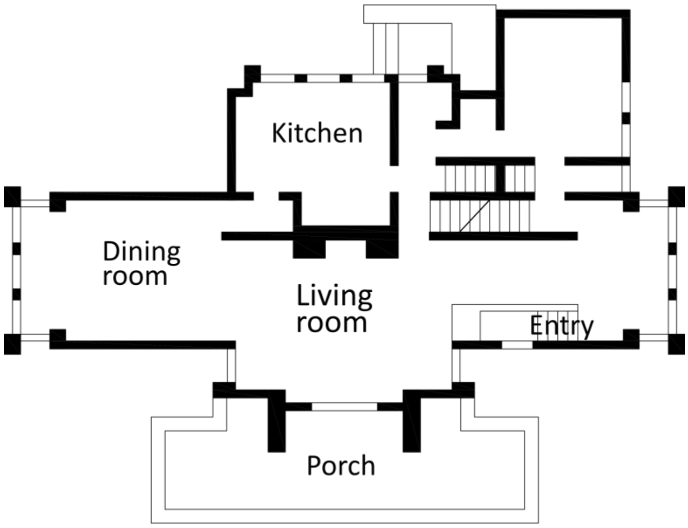
Primal axial map



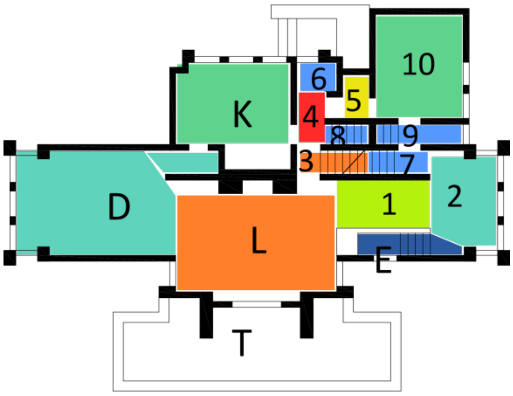
Dual axial map

24. Sutton, house for Harvey,

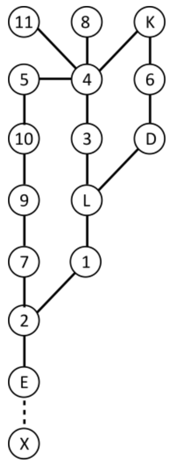
Scheme #3 in 1905 in McCook, Nebraska (Futugawa, 1987a, p. 175).



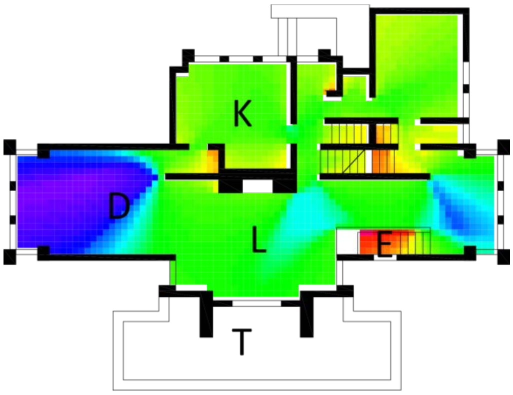
First floor plan



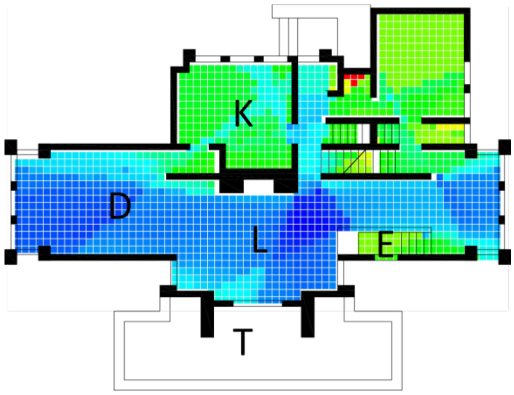
Convex map



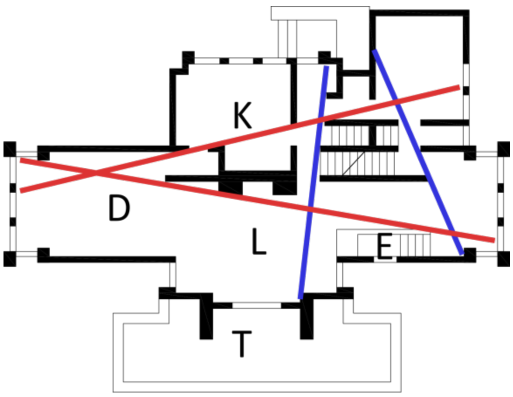
Justified plan graph



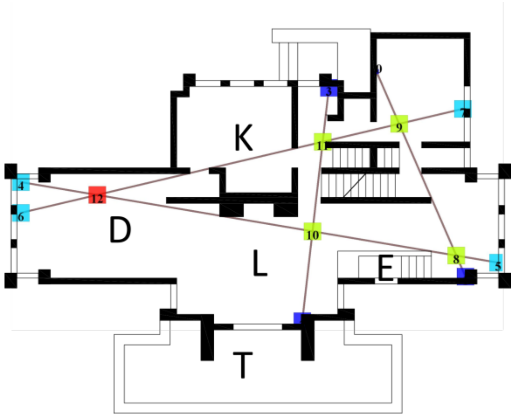
Angular mean depth



Step mean depth



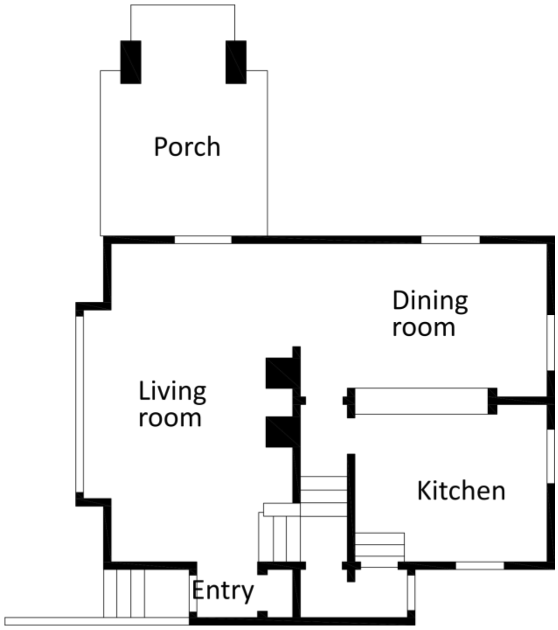
Primal axial map



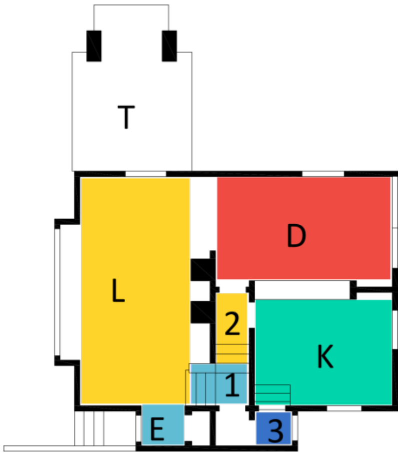
Dual axial map

25. Waller, House for Edward

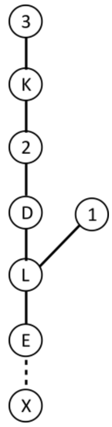
Designed in 1909 as *renthouse*, scheme #1, in River Forest, Illinois (Futugawa, 1987b, p. 116)



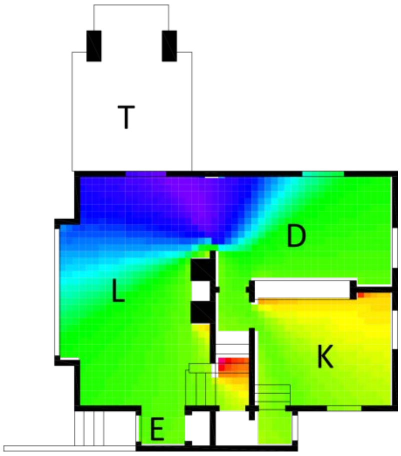
First floor plan



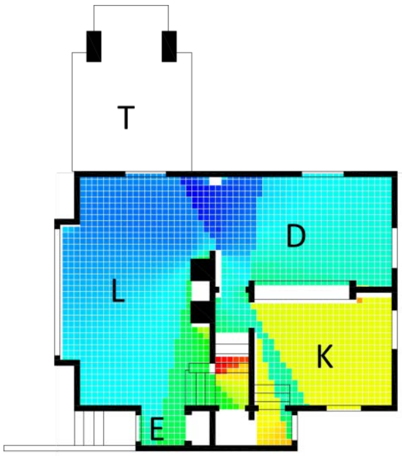
Convex map



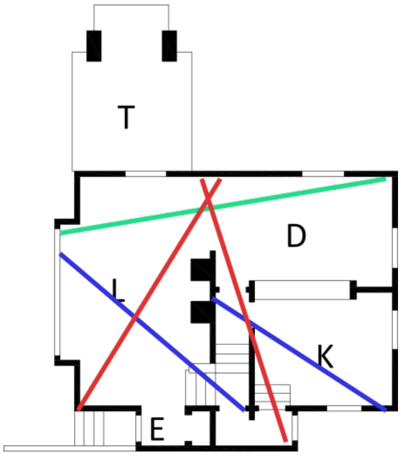
Justified plan graph



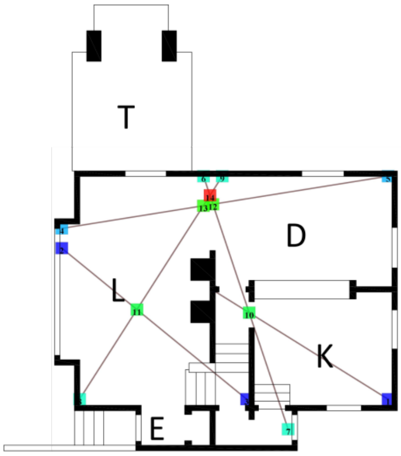
Angular mean depth



Step mean depth



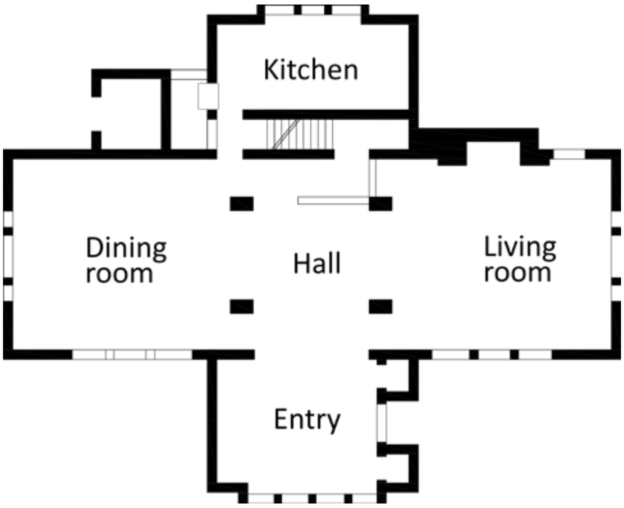
Primal axial map



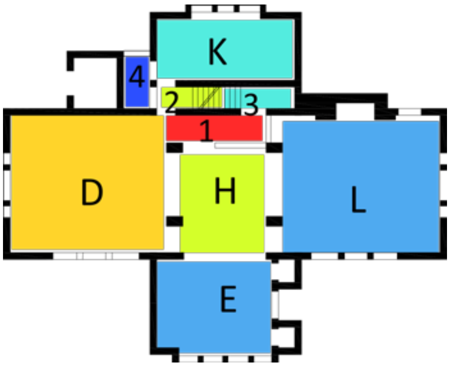
Dual axial map

26. Walser, house for J. J.,

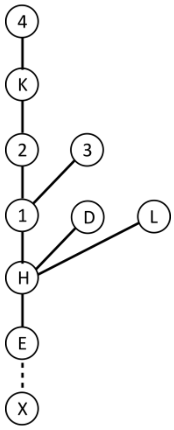
Built in 1903 in Chicago, Illinois (Futugawa, 1987a, p. 68).



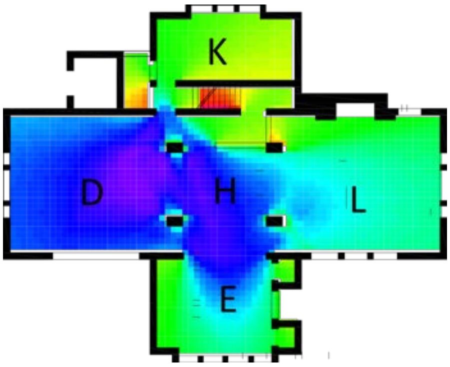
First floor plan



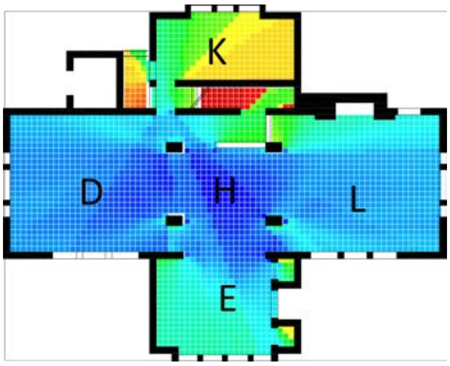
Convex map



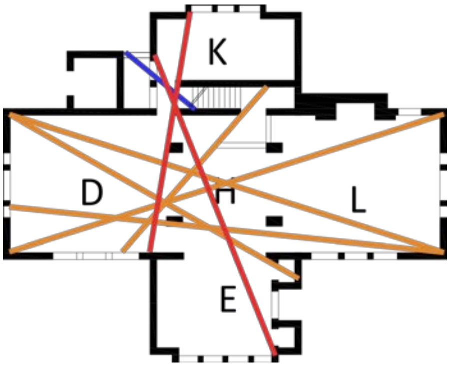
Justified plan graph



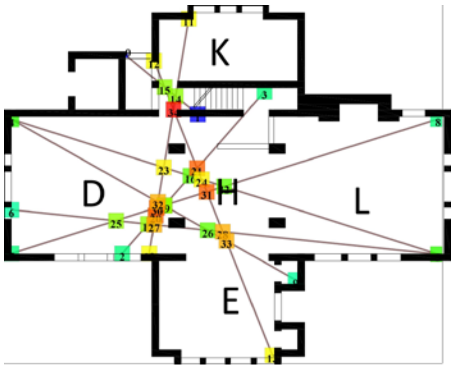
Angular mean depth



Step mean depth



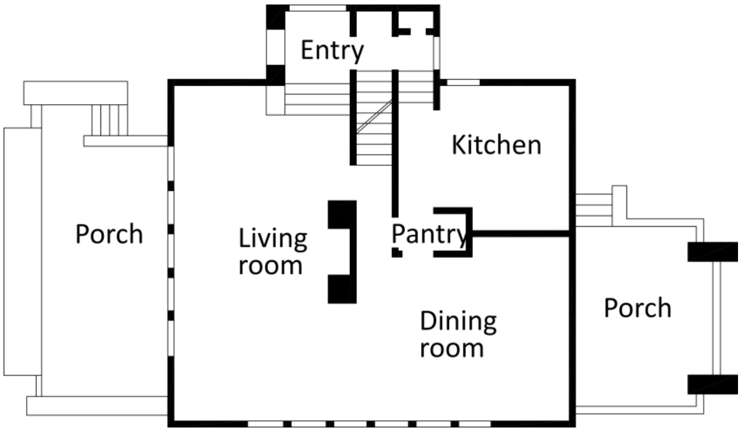
Primal axial map



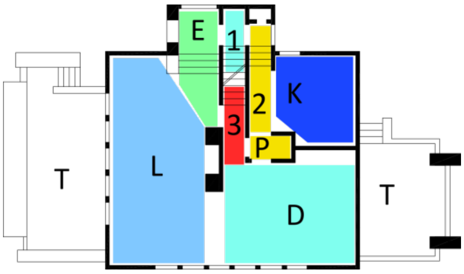
Dual axial map

27. Ziegler, house for Rev. J. R.,

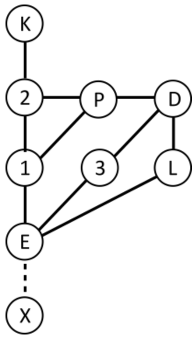
Built in 1910 in Frankfort, Kentucky (Futugawa, 1987b, p. 128).



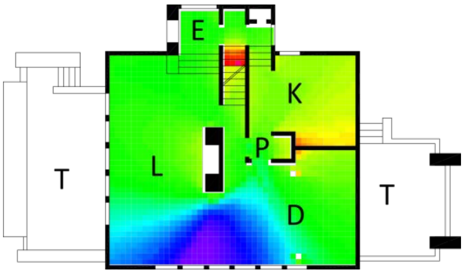
First floor plan



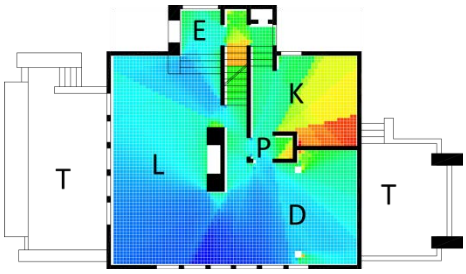
Convex map



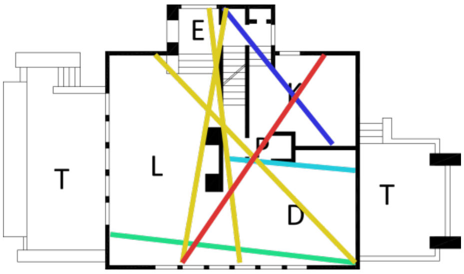
Justified plan graph



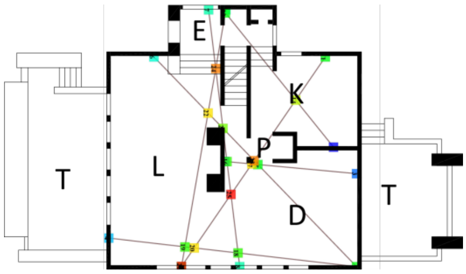
Angular mean depth



Step mean depth



Primal axial map



Dual axial map

II. Detailed results

II.1. Victorian houses

Table II.1. Relative size of major spaces of Victorian houses.

Plate No.	Parlour	Dining	Hall	Kitchen	Pantry	Entry	Sum
2	24.8%	25.7%		21.9%	4.0%		72.4%
5	25.8%	22.4%	7.7%	16.7%	6.9%	3.9%	72.5%
8	25.2%	20.4%	14.5%	20.9%			81.1%
9	27.3%	24.2%	5.5%	25.7%	4.3%	3.9%	82.7%
10	27.1%	23.6%	10.3%	22.4%	3.2%		83.4%
18	20.3%	21.0%	9.4%	15.3%	3.6%	2.4%	66.0%
25	23.1%	24.7%	5.4%	20.3%	3.2%	3.5%	73.5%
27	25.0%	22.9%	18.9%	18.2%	5.7%		85.0%
40	21.7%	21.6%	8.3%	19.0%	5.9%	7.1%	70.6%
43	23.0%	17.3%	7.4%	9.7%	3.3%	1.8%	57.3%
49	26.7%	28.1%	7.6%	27.5%		1.3%	89.8%
52	20.3%	20.1%	12.6%	15.3%	4.6%	2.2%	68.2%
55	22.0%	20.6%	18.4%	18.7%	4.9%		79.8%
60	26.6%	24.7%		12.0%	3.1%		63.3%
75	25.1%	19.9%	6.5%	14.4%	2.8%	2.1%	65.8%
Mean	24.3%	22.5%	10.2%	18.5%	4.3%	3.1%	74.1%
SD	2.3%	2.7%	4.4%	4.7%	1.2%	2.6%	8.9%

Table II.2. The integration values of major spaces in Victorian houses excluding the exterior.

Plate No.	Parlour	Dining	Hall	Kitchen	Pantry	Entry
2	0.40	0.62		0.98	1.37	
5	0.73	0.84	1.57	0.73	1.22	0.64
8	0.47	1.22	0.73	0.64		
9	0.86	0.86	1.72	1.72	0.68	0.86
10	1.22	1.10	2.75	2.20	1.22	
18	1.05	1.25	2.02	1.38	1.09	0.97
25	1.20	1.56	2.23	1.95	0.87	0.74
27	0.52	1.00	0.84	0.84	1.00	
40	1.14	1.72	6.89	0.68	1.72	0.98
43	0.83	1.50	1.46	1.08	0.69	0.83
49	1.01	1.69	1.69	0.46		0.63
52	1.06	1.38	1.06	1.30	1.17	0.67
55	0.82	1.20	1.47	1.47	1.20	
60	0.66	1.20		1.65	0.78	
75	1.22	1.22	1.89	1.30	0.94	0.90
Mean	0.88	1.22	2.02	1.23	1.07	0.80
SD	0.27	0.30	1.50	0.50	0.28	0.13

Table II.3. The integration values of major spaces in Victorian houses including the exterior (X).

Plate No.	Parlour	Dining	Hall	Kitchen	Pantry	Entry	X
2	0.52	0.80		0.88	1.26		0.52
5	0.87	0.82	1.47	0.69	1.10	0.78	0.51
8	0.55	1.20	0.88	0.63			0.55
9	0.88	0.80	1.77	1.47	0.68	1.10	0.59
10	1.32	1.10	3.30	2.21	1.20		1.02
18	1.08	1.27	2.09	1.33	1.08	1.08	0.69
25	1.21	1.39	2.02	1.65	0.82	0.86	0.56
27	0.60	1.01	1.20	0.83	1.20		0.60
40	1.10	1.47	4.43	0.68	1.47	1.26	0.63
43	0.87	1.53	1.53	1.07	0.70	0.92	0.63
49	0.98	1.37	1.72	0.48	0.74	0.86	0.49
52	1.09	1.14	1.31	1.19	1.09	0.75	0.53
55	0.92	1.30	1.74	0.42	1.20		0.82
60	0.74	1.04		1.42		0.54	0.40
75	1.23	1.17	1.96	1.23	0.90	1.02	0.65
Mean	0.93	1.16	1.96	1.08	0.95	0.92	0.61
SD	0.24	0.23	0.91	0.47	0.29	0.20	0.14

Table II.4. The relative isovist area of major spaces in Victorian houses (normalised by space sizes).

Plate No.	Parlour	Dining	Hall	Kitchen	Pantry	Entry	Holistic
2	18.2%	16.7%		6.4%	17.2%		32.9%
5	19.2%	19.9%	35.6%	10.5%	23.8%	27.9%	36.6%
8	10.0%	11.0%	21.8%	5.7%			31.3%
9	20.6%	23.2%	32.8%	13.2%	10.9%	21.5%	41.1%
10	17.6%	20.0%	24.4%	10.4%	33.2%		37.4%
18	9.9%	14.4%	24.2%	6.1%	23.4%	13.0%	25.9%
25	20.7%	21.4%	25.1%	9.7%	10.8%	15.5%	35.4%
27	18.8%	16.6%	31.7%	5.2%	12.6%		36.6%
40	20.0%	19.3%	31.4%	5.2%	20.7%	13.2%	32.7%
43	8.7%	6.7%	29.3%	4.1%	4.2%	21.5%	21.7%
49	20.4%	18.2%	26.7%	2.3%		17.4%	39.0%
52	24.2%	18.1%	25.3%	7.0%	15.8%	26.6%	31.4%
55	22.2%	18.7%	20.4%	7.0%	16.9%		33.5%
60	12.3%	14.7%		16.9%	7.5%		30.8%
75	18.6%	19.7%	28.9%	7.6%	20.0%	11.1%	31.3%
Mean	17.4%	17.2%	27.5%	7.8%	16.7%	18.6%	33.2%
SD	4.7%	4.1%	4.4%	3.6%	7.4%	5.7%	4.8%

Table II.5. The step mean depth (isovist map) of major spaces in Victorian houses.

Plate No.	Parlour	Dining	Hall	Kitchen	Pantry	Entry	Holistic
2	2.09	1.76		2.36	2.10	0.52	2.12
5	1.71	1.68	2.01	1.64	1.74	1.75	1.79
8	2.24	1.91	1.93	2.33			2.21
9	1.58	1.59	1.68	1.60	1.85	2.17	1.68
10	1.63	1.63	1.69	1.77	1.70		1.71
18	2.02	1.76	1.83	2.19	1.96	2.02	2.03
25	1.64	1.57	1.80	1.75	2.07	1.91	1.73
27	2.05	1.77	1.74	2.54	2.19		2.07
40	1.71	1.61	1.59	1.99	1.80	1.94	1.79
43	2.14	2.00	1.75	2.71	2.46	1.87	2.26
49	1.70	1.60	2.02	2.07		2.24	1.84
52	1.71	1.73	1.75	1.99	1.95	1.83	1.88
55	1.71	1.68	1.72	1.91	1.96		1.85
60	2.03	1.71		1.98	2.66		2.05
75	1.61	1.66	1.67	1.91	1.90	2.00	1.81
Mean	1.84	1.71	1.78	2.05	2.03	1.82	1.92
SD	0.22	0.11	0.13	0.31	0.27	0.46	0.18

Table II.6. The step mean depth (isovist map) of major spaces in Victorian houses (normalised by space sizes).

Plate No.	Parlour	Dining	Hall	Kitchen	Pantry	Entry
2	2.45	2.02		2.74	2.15	
5	1.96	1.88	2.09	1.77	1.79	1.78
8	2.66	2.14	2.09	2.68		
9	1.80	1.78	1.72	1.81	1.89	2.22
10	1.86	1.82	1.77	1.99	1.72	
18	2.28	1.96	1.91	2.41	1.99	2.05
25	1.83	1.76	1.85	1.94	2.10	1.94
27	2.40	1.99	1.92	2.88	2.26	
40	1.90	1.78	1.65	2.23	1.85	2.02
43	2.48	2.20	1.80	2.90	2.51	1.89
49	1.96	1.83	2.10	2.47		2.26
52	1.89	1.91	1.86	2.16	1.99	1.85
55	1.91	1.86	1.88	2.12	2.01	
60	2.40	1.94		2.12	2.71	
75	1.82	1.82	1.71	2.06	1.93	2.02
Mean	2.11	1.91	1.87	2.29	2.07	2.00
SD	0.29	0.13	0.14	0.36	0.27	0.15

Table II.7. The angular mean depth (isovist map) of major spaces in Victorian houses.

Plate No.	Parlour	Dining	Hall	Kitchen	Pantry	Entry	Holistic
2	0.66	0.44		0.91	0.60	0.52	0.72
5	0.34	0.37	0.23	0.57	0.34	0.28	0.41
8	0.88	0.55	0.52	0.83			0.81
9	0.31	0.30	0.29	0.39	0.68	0.38	0.38
10	0.31	0.36	0.32	0.47	0.30		0.39
18	0.44	0.33	0.46	0.71	0.42	0.71	0.52
25	0.32	0.27	0.36	0.44	0.53	0.47	0.38
27	0.81	0.40	0.54	1.06	0.99		0.78
40	0.37	0.39	0.28	0.61	0.44	0.45	0.47
43	0.75	0.62	0.43	1.19	1.22	0.58	0.82
49	0.40	0.43	0.48	0.74		0.56	0.54
52	0.35	0.36	0.37	0.53	0.42	0.40	0.47
55	0.38	0.38	0.38	0.54	0.51		0.50
60	0.65	0.42		0.73	1.02		0.69
75	0.32	0.29	0.32	0.48	0.41	0.63	0.43
Mean	0.49	0.39	0.38	0.68	0.71	0.50	0.55
SD	0.20	0.09	0.09	0.23	0.47	0.12	0.16

Table II.8. The angular mean depth (isovist map) of major spaces in Victorian houses (normalised by space sizes).

Plate No.	Parlour	Dining	Hall	Kitchen	Pantry	Entry
2	0.88	0.59		1.17	0.63	
5	0.46	0.48	0.25	0.69	0.37	0.29
8	1.17	0.70	0.61	1.05		
9	0.43	0.40	0.31	0.52	0.71	0.39
10	0.42	0.47	0.35	0.60	0.31	
18	0.55	0.42	0.51	0.84	0.44	0.73
25	0.42	0.35	0.38	0.55	0.54	0.49
27	1.08	0.51	0.67	1.30	1.05	
40	0.47	0.49	0.31	0.76	0.47	0.48
43	0.97	0.74	0.46	1.32	1.27	0.59
49	0.54	0.60	0.52	1.02		0.57
52	0.44	0.45	0.42	0.63	0.44	0.41
55	0.49	0.48	0.46	0.67	0.54	
60	0.89	0.56		0.83	1.05	
75	0.43	0.36	0.34	0.56	0.42	0.64
Mean	0.64	0.51	0.43	0.83	0.63	0.51
SD	0.26	0.11	0.12	0.26	0.29	0.13

Table II.9. The step interspatial depth values in Victorian houses.

Plate No.	L-D	L-K	D-K	E-L	E-D	E-K
2	1.46	3.45	2.56			
5	1.43	2.60	2.34	1.81	1.85	2.04
8	2.52	3.37	1.94			
9	1.51	1.76	2.09	1.75	2.12	1.88
10	1.5	2.18	2.08			
18	1.75	2.92	2.18	1.95	2.30	2.31
25	1.48	2.11	1.82	1.97	1.84	2.06
27	1.9	3.68	2.46			
40	1.48	2.53	2.11	1.96	2.04	2.26
43	2.26	3.56	2.31	1.7	1.75	2.59
49	1.46	2.54	2.21	1.82	1.87	3.36
52	1.4	2.40	2.21	1.76	1.74	2.03
55	1.46	2.30	2.02			
60	1.61	2.70	1.83			
75	1.51	2.13	1.96	2.09	2.03	1.95
Mean	1.65	2.68	2.14	1.87	1.95	2.28
SD	0.32	0.57	0.21	0.12	0.18	0.43

Table II.10. The angular interspatial depth values in Victorian houses.

Plate No.	L-D	L-K	D-K	E-L	E-D	E-K
2	0.16	1.59	0.95			
5	0.17	0.8	0.97	0.19	0.43	0.42
8	0.83	1.89	0.38			
9	0.17	0.38	0.63	0.45	0.45	0.30
10	0.19	0.57	0.77			
18	0.30	0.94	0.55	0.55	1.10	0.99
25	0.22	0.59	0.45	0.32	0.51	0.46
27	0.33	2.14	0.64			
40	0.22	0.72	0.88	0.28	0.6	0.53
43	0.58	2.16	0.81	0.28	0.59	1.32
49	0.16	0.88	1.03	0.25	0.52	0.95
52	0.13	0.65	0.65	0.21	0.34	0.47
55	0.17	0.71	0.56			
60	0.20	1.54	0.62			
75	0.19	0.48	0.46	0.47	0.98	0.39
Mean	0.27	1.07	0.69	0.33	0.61	0.65
SD	0.18	0.60	0.20	0.12	0.24	0.33

Table II.11. Position of highly integrated axial lines (HIALs) in Victorian houses.

Plate No.	Parlour	Dining	Hall	Kitchen	Pantry	Entry
2		●			●	
5	●	●	●	●	●	●
8		●	●			
9	●	●	●	●	●	●
10	●		●	●		
18			●	●		
25		●		●		
27		●		●	●	
40	●	●	●	●	●	●
43		●	●		●	●
49	●	●		●		
52		●		●		
55	●	●	●	●	●	
60		●		●		
75	●		●	●		
Occurrence	47%	80%	60%	80%	47%	27%

Table II.12. Position of highly integrated intersections (HIXs) in Victorian houses.

Plate No.	Parlour	Dining	Hall	Kitchen	Pantry	Entry
2		●*				
5		●		●	●	
8		●				
9			●	●o*		
10	●	●	●	●		
18		o	●	●		
25		●o	●	●o		
27		●		●	●	
40	●	●o	o		o	
43		●		●	●	
49				●		
52	●	●	●	●o		
55	●o					
60	●o	●				
75	●	●	●	●o	●	
o	13%	20%	7%	27%	7%	0%
●	40%	73%	40%	67%	27%	0%

* o = between two spaces (side)
** ● = middle of space (side)

II.2. Prairie houses

Table II.13. Relative size of major spaces of Prairie houses.

ST*	House	Living	Dining	Hall	Kitchen	Pantry	Entry	Sum
IA1	$5000	41.7%	22.2%	3.3%	17.4%		3.1%	87.7%
IA1	Adams	25.1%	16.8%	5.3%	11.3%	5.7%	3.3%	67.5%
IA2	Adams #1	35.5%	19.9%		10.7%	1.1%	7.1%	74.1%
IB2	Adams #2	35.7%	26.7%	5.1%	11.4%	3.3%		82.2%
IA1	Baker	39.8%	24.1%		11.7%		3.0%	85.8%
IB1	Baldwin	34.2%	18.9%	10.7%	11.5%	3.8%		79.1%
IB2	Barnes	23.9%	24.2%	11.4%	12.7%		14.5%	86.7%
IB2	Brown	33.4%	23.5%	9.8%	11.9%	4.6%	2.0%	85.2%
IB2	DeRhodes	22.7%	22.6%	10.6%	11.5%		11.0%	78.4%
IB1	Fuller	29.4%	19.3%	5.3%	14.4%	8.3%	4.9%	76.8%
IA1	Gale	33.7%	19.1%	5.6%	13.1%	1.7%	1.7%	74.9%
IIA	Kellogg	24.8%	18.0%	10.5%	16.0%	4.1%	13.1%	57.7%
IIA	Larwill	33.3%	22.0%	4.8%	12.8%	4.2%	1.9%	86.4%
IB1	Little 1902	21.5%	18.1%	9.4%	10.1%	5.7%	4.0%	78.9%
IIA	Little 1908	26.5%	17.2%	11.9%	9.3%	3.3%	3.7%	68.8%
IIB	Martin	24.0%	17.9%	10.5%	11.6%	1.8%	4.6%	68.2%
IIB	May	29.6%	16.6%	7.3%	8.7%	5.7%	2.1%	70.4%
IIB	Millard	33.3%	14.5%	12.0%	10.3%			70.0%
IA1	Nicholas	39.8%	22.5%		13.2%		3.6%	70.2%
IA1	Roberts	31.7%	20.6%	9.0%	18.7%		2.5%	79.1%
IIA	Ross	36.9%	21.6%		15.7%	2.1%	3.6%	80.0%
IA1	Stockman	39.8%	24.6%		13.7%		4.5%	79.8%
IIA	Sutton #1	37.8%	15.2%	6.5%	15.0%	1.5%	3.0%	82.6%
IIA	Sutton #3	21.2%	20.3%		12.0%	1.5%	2.7%	72.5%
IA2	Waller	40.7%	26.6%		20.7%		2.4%	90.4%
IB2	Walser	24.0%	24.9%	11.3%	10.9%		13.2%	84.3%
IA1	Ziegler	37.8%	25.4%		14.8%	1.9%	3.8%	83.7%
	Mean	31.8%	20.9%	8.5%	13.0%	3.5%	5.1%	82.8%
	SD	6.47%	3.40%	2.75%	2.79%	1.95%	3.98%	

* subtypes

Table II.14. The integration values of major spaces in Prairie houses excluding the exterior.

ST*	House	Living	Dining	Hall	Kitchen	Pantry	Entry	I**
IA1	$5000	1.69	0.74	1.27	1.01		1.01	0.91
IA1	Adams	1.06	1.13	1.51	1.01	0.91	0.86	0.84
IA2	Adams #1	0.78	0.69		0.37	0.51	1.02	0.86
IB2	Adams #2	0.78	1.10	1.83	0.84	0.78		0.94
IA1	Baker	1.14	1.72		0.76		1.14	0.82
IB1	Baldwin	0.46	0.97	0.65	0.71	0.87		0.69
IB2	Barnes	0.63	1.47	1.26	0.73		0.63	0.92
IB2	Brown	1.00	1.10	1.83	0.45	0.68	0.78	0.90
IB2	DeRhodes	0.84	1.22	1.22	1.10		0.64	0.84
IB1	Fuller	1.10	0.88	1.32	0.94	0.83	1.10	0.94
IA1	Gale	0.64	1.22	1.37	0.73	1.22	0.68	0.95
IIA	Kellogg	0.61	1.00	1.10	0.92	0.92	1.10	0.86
IIA	Larwill	1.22	1.57	2.75	1.22	1.10	0.92	0.91
IB1	Little 1902	0.87	1.23	1.47	0.71	0.98	0.81	0.90
IIA	Little 1908	1.07	1.29	1.61	0.64	1.34	0.89	0.88
IIB	Martin	0.98	1.12	1.81	0.87	0.94	0.90	0.91
IIB	May	0.65	1.14	1.01	0.73	1.31	0.75	0.72
IIB	Millard	1.11	0.71	0.87	0.87	0.69		0.81
IA1	Nicholas	0.44	0.59		0.98		0.59	0.57
IA1	Roberts	0.91	1.37	1.57	0.68		1.57	0.98
IIA	Ross	0.88	0.88		0.98	0.88	0.98	0.86
IA1	Stockman	1.14	1.14		0.68		0.86	0.89
IIA	Sutton #1	1.20	0.88	1.32	1.20	0.88	0.69	0.97
IIA	Sutton #3	1.12	0.78		0.84	0.78	0.56	0.75
IA2	Waller	0.84	1.01		0.56		0.46	0.76
IB2	Walser	0.63	1.47	1.26	0.73		0.63	0.92
IA1	Ziegler	0.86	1.15		0.68	1.72	1.37	0.89
	Mean	0.91	1.10	1.39	0.81	1.00	0.87	0.86
	SD	0.27	0.27	0.43	0.20	0.27	0.26	0.09

* subtypes
** intelligibility

Table II.15. The integration values of major spaces of Prairie houses including the exterior (X).

ST*	House	Living	Dining	Hall	Kitchen	Pantry	Entry	X
IA1	$5000	1.37	0.86	1.14	1.14		1.37	0.62
IA1	Adams	1.09	1.09	1.60	0.94	0.86	0.99	0.63
IA2	Adams #1	0.82	0.71		0.39	0.52	1.20	0.68
IB2	Adams #2	0.88	1.20	2.21	0.82	0.82		0.88
IA1	Baker	1.26	1.47	1.26	0.73		1.47	0.68
IB1	Baldwin	0.51	1.01	0.75	0.69	0.86		0.51
IB2	Barnes	0.68	1.37	1.37	0.68		0.78	0.50
IB2	Brown	1.02	1.10	1.98	0.47	0.69	0.94	0.57
IB2	DeRhodes	0.95	1.22	1.51	0.82		1.06	0.64
IB1	Fuller	1.20	0.97	1.42	0.92	0.87	1.30	0.71
IA1	Gale	0.66	1.10	1.47	0.69	1.10	0.82	0.53
IIA	Kellogg	0.61	1.00	1.10	0.96	0.91	1.10	0.61
IIA	Larwill	1.32	1.65	2.21	1.10	1.10	1.10	0.63
IB1	Little 1902	0.90	1.25	1.55	0.71	0.97	0.90	0.61
IIA	Little 1908	1.07	1.26	1.68	0.64	1.30	0.98	0.66
IIB	Martin	1.10	1.14	1.88	0.85	0.94	1.01	0.65
IIB	May	0.68	1.12	1.04	0.71	1.27	0.83	0.58
IIB	Millard	1.21	0.79	1.01	0.82			0.62
IA1	Nicholas	0.52	0.65		1.00		0.73	0.49
IA1	Roberts	0.94	1.32	1.65	0.69		1.89	0.63
IIA	Ross	1.00	0.91		0.91	0.84	1.22	0.65
IA1	Stockman	1.26	1.10		0.63		1.10	0.59
IIA	Sutton #1	1.20	0.87	1.42	1.04	0.82	0.82	0.54
IIA	Sutton #3	1.10	0.77		0.77	0.75	0.62	0.47
IA2	Waller	0.98	0.98		0.53		0.62	0.40
IB2	Walser	0.67	1.37	1.37	0.68		0.78	0.50
IA1	Ziegler	0.98	1.10	2.21	0.68	1.47	1.78	0.73
	Mean	0.96	1.09	1.52	0.78	0.95	1.06	0.60
	SD	0.24	0.23	0.40	0.18	0.22	0.32	0.09

* subtypes

Table II.16. The relative isovist area of major spaces in Prairie houses (normalised by space sizes).

ST*	House	Living	Dining	Hall	Kitchen	Pantry	Entry	Holistic
IA1	$5000	14.2%	17.7%	24.6%	2.2%		12.6%	41.1%
IA1	Adams	6.1%	14.4%	25.3%	4.1%	11.0%	16.2%	22.5%
IA2	Adams #1	22.0%	29.9%		4.2%	15.2%	5.8%	42.8%
IB2	Adams #2	16.8%	23.0%	58.4%	2.8%	10.4%		40.9%
IA1	Baker	10.7%	14.7%		1.5%		18.4%	36.9%
IB1	Baldwin	8.3%	11.5%	24.4%	3.3%	7.0%		29.7%
IB2	Barnes	26.4%	29.3%	53.4%	4.2%		21.9%	42.6%
IB2	Brown	15.4%	20.1%	36.5%	1.2%	8.2%	20.3%	37.3%
IB2	DeRhodes	25.1%	25.7%	47.5%	3.1%		22.9%	36.6%
IB1	Fuller	12.6%	15.7%	37.9%	8.0%	9.6%	38.1%	30.3%
IA1	Gale	14.7%	24.5%	16.6%	4.1%	19.2%	3.9%	35.2%
IIA	Kellogg	20.3%	23.8%	49.2%	6.9%	5.5%	27.4%	36.7%
IIA	Larwill	13.0%	14.8%	28.1%	7.6%	11.1%	19.3%	34.3%
IB1	Little 1902	16.2%	16.8%	38.1%	1.8%	6.1%	16.2%	29.0%
IIA	Little 1908	17.9%	14.2%	17.8%	0.6%	10.9%	26.7%	28.2%
IIB	Martin	17.4%	18.9%	41.0%	3.9%	13.8%	12.9%	32.6%
IIB	May	17.8%	16.9%	47.5%	3.8%	5.0%	1.4%	32.2%
IIB	Millard	10.6%	14.2%	18.1%	3.7%			28.6%
IA1	Nicholas	8.6%	13.2%		6.1%		14.9%	35.2%
IA1	Roberts	13.8%	17.6%	35.1%	1.2%		18.0%	33.4%
IIA	Ross	18.5%	37.4%		6.2%	15.1%	46.5%	38.5%
IA1	Stockman	12.8%	16.4%		1.4%		15.9%	38.1%
IIA	Sutton #1	9.5%	16.4%	26.7%	7.6%	12.5%	3.7%	31.3%
IIA	Sutton #3	26.1%	25.5%		4.0%	14.1%	4.1%	29.9%
IA2	Waller	15.5%	19.2%		2.5%		38.0%	43.6%
IB2	Walser	29.9%	30.2%	55.6%	2.5%	17.2%	23.4%	45.1%
IA1	Ziegler	18.4%	23.4%		5.9%	20.2%	34.9%	43.3%
	Mean	16.6%	19.9%	36.7%	4.1%	12.0%	20.4%	35.0%
	SD	5.5%	6.4%	12.6%	2.3%	4.7%	12.9%	5.3%

* subtypes

Table II.17. The step mean depth (isovist map) of major spaces in Prairie houses.

ST*	House	Living	Dining	Hall	Kitchen	Pantry	Entry	Holistic
IA1	$5000	1.58	1.74	1.79	2.31		2.09	1.79
IA1	Adams	2.06	1.78	1.85	2.32	2.12	2.41	2.11
IA2	Adams #1	1.59	1.69		2.46	2.26	2.45	1.89
IB2	Adams #2	1.62	1.62	1.39	2.26	2.05		1.78
IA1	Baker	1.66	1.72		2.56		1.95	1.85
IB1	Baldwin	2.13	2.06	2.04	2.79	2.53		2.37
IB2	Barnes	1.66	1.54	1.42	2.28		1.70	1.75
IB2	Brown	1.73	1.64	1.62	2.50	2.30	1.95	1.89
IB2	DeRhodes	1.70	1.61	1.59	2.37		1.86	1.89
IB1	Fuller	1.69	1.79	1.88	1.88	2.18	1.68	1.86
IA1	Gale	1.82	1.68	1.97	2.41	1.96	2.73	2.02
IIA	Kellogg	1.73	1.67	1.61	2.05	2.42	1.67	1.84
IIA	Larwill	1.69	1.68	1.72	2.13	2.18	1.98	1.80
IB1	Little 1902	2.10	1.79	1.82	3.23	2.48	2.28	2.24
IIA	Little 1908	1.87	2.02	2.07	3.04	2.01	2.31	2.24
IIB	Martin	1.80	1.73	1.55	2.35	2.17	2.03	1.91
IIB	May	1.70	1.76	1.57	2.45	2.18	2.51	1.93
IIB	Millard	1.81	2.08	1.96	2.35			2.10
IA1	Nicholas	1.76	1.78		2.24		1.99	1.94
IA1	Roberts	1.71	1.66	1.71	2.34		1.99	1.89
IIA	Ross	1.68	1.75		2.02	2.20	1.66	1.90
IA1	Stockman	1.62	1.74		2.43		2.04	1.84
IIA	Sutton #1	1.66	1.86	1.73	1.98	2.11	2.29	1.90
IIA	Sutton #3	1.75	1.79		2.31	2.38	2.66	2.07
IA2	Waller	1.65	1.72		2.48		1.95	1.89
IB2	Walser	1.61	1.51	1.41	2.39		1.74	1.73
IA1	Ziegler	1.53	1.56		2.21	1.87	1.71	1.68
	Mean	1.74	1.74	1.72	2.38	2.20	2.09	1.93
	SD	0.15	0.14	0.20	0.29	0.17	0.32	0.16

* subtypes

Table II.18. The step mean depth (isovist map) of major spaces in Prairie houses (normalised by space sizes).

ST*	House	Living	Dining	Hall	Kitchen	Pantry	Entry
IA1	$5000	2.00	2.24	1.85	2.79		2.16
IA1	Adams	2.75	2.14	1.95	2.62	2.25	2.49
IA2	Adams #1	2.46	2.11		2.76	2.29	2.64
IB2	Adams #2	2.51	2.21	1.47	2.55	2.12	
IA1	Baker	2.75	2.26		2.89		2.01
IB1	Baldwin	3.24	2.54	2.28	3.16	2.63	
IB2	Barnes	2.18	2.03	1.61	2.61		1.99
IB2	Brown	2.61	2.14	1.80	2.84	2.41	1.99
IB2	DeRhodes	2.20	2.08	1.78	2.67		2.09
IB1	Fuller	2.40	2.22	1.99	2.19	2.38	1.77
IA1	Gale	2.74	2.08	2.08	2.78	2.00	2.78
IIA	Kellogg	2.30	2.03	1.80	2.44	2.52	1.92
IIA	Larwill	2.53	2.16	1.81	2.45	2.27	2.02
IB1	Little 1902	2.67	2.19	2.01	3.59	2.63	2.37
IIA	Little 1908	2.54	2.43	2.35	3.36	2.08	2.40
IIB	Martin	2.38	2.11	1.73	2.66	2.21	2.13
IIB	May	2.41	2.11	1.69	2.69	2.31	2.56
IIB	Millard	2.72	2.43	2.23	2.62		
IA1	Nicholas	2.93	2.29		2.58		2.07
IA1	Roberts	2.50	2.09	1.87	2.88		2.04
IIA	Ross	2.65	2.24		2.39	2.24	1.72
IA1	Stockman	2.68	2.31		2.82		2.13
IIA	Sutton #1	2.66	2.19	1.85	2.33	2.14	2.36
IIA	Sutton #3	2.22	2.24		2.62	2.41	2.73
IA2	Waller	2.78	2.35		3.13		1.99
IB2	Walser	2.11	2.01	1.59	2.68		2.00
IA1	Ziegler	2.46	2.09		2.59	1.91	1.78
	Mean	2.53	2.20	1.88	2.73	2.28	2.19
	SD	0.26	0.13	0.23	0.30	0.20	0.30

* subtypes

Table II.19. The angular mean depth (isovist map) of major spaces in Prairie houses.

ST*	House	Living	Dining	Hall	Kitchen	Pantry	Entry	Holistic
IA1	$5000	0.34	0.38	0.51	0.79		0.51	0.45
IA1	Adams	0.59	0.45	0.47	0.77	0.59	0.79	0.65
IA2	Adams #1	0.38	0.36		1.00	0.85	1.11	0.57
IB2	Adams #2	0.29	0.35	0.20	0.81	0.66		0.44
IA1	Baker	0.32	0.37		0.91		0.50	0.48
IB1	Baldwin	0.82	0.50	0.78	1.53	1.33		0.99
IB2	Barnes	0.40	0.22	0.23	0.79		0.35	0.44
IB2	Brown	0.50	0.32	0.40	1.38	0.78	0.52	0.63
IB2	DeRhodes	0.30	0.40	0.32	0.82		0.37	0.51
IB1	Fuller	0.35	0.50	0.30	0.44	0.67	0.30	0.50
IA1	Gale	0.46	0.30	0.63	0.75	0.51	1.15	0.57
IIA	Kellogg	0.33	0.28	0.38	0.50	0.72	0.29	0.42
IIA	Larwill	0.28	0.35	0.37	0.54	0.61	0.44	0.38
IB1	Little 1902	0.58	0.45	0.38	1.25	0.86	0.47	0.70
IIA	Little 1908	0.42	0.45	0.59	1.06	0.56	0.61	0.68
IIB	Martin	0.45	0.32	0.26	0.71	0.89	0.56	0.54
IIB	May	0.41	0.39	0.31	0.78	0.95	1.24	0.56
IIB	Millard	0.48	0.44	0.54	0.85			0.61
IA1	Nicholas	0.44	0.44		0.71		0.54	0.55
IA1	Roberts	0.36	0.38	0.34	0.82		0.58	0.49
IIA	Ross	0.31	0.39		0.52	0.80	0.29	0.48
IA1	Stockman	0.33	0.44		0.86		0.59	0.49
IIA	Sutton #1	0.40	0.37	0.44	0.50	0.87	0.83	0.51
IIA	Sutton #3	0.50	0.32		0.68	0.95	1.66	0.61
IA2	Waller	0.42	0.44		0.99		0.69	0.59
IB2	Walser	0.35	0.20	0.24	0.85		0.33	0.41
IA1	Ziegler	0.28	0.27		0.73	0.45	0.31	0.39
	Mean	0.41	0.37	0.40	0.83	0.77	0.64	0.54
	SD	0.12	0.07	0.14	0.25	0.21	0.35	0.12

* subtypes

Table II.20. The angular mean depth (isovist map) of major spaces in Prairie houses (normalised by space sizes).

ST*	House	Living	Dining	Hall	Kitchen	Pantry	Entry
IA1	$5000	0.58	0.48	0.53	0.96		0.53
IA1	Adams	0.79	0.54	0.50	0.87	0.63	0.81
IA2	Adams #1	0.58	0.45		1.12	0.86	1.20
IB2	Adams #2	0.45	0.48	0.21	0.91	0.68	
IA1	Baker	0.53	0.49		1.03		0.51
IB1	Baldwin	1.25	0.62	0.88	1.73	1.38	
IB2	Barnes	0.53	0.30	0.26	0.91		0.41
IB2	Brown	0.75	0.42	0.44	1.57	0.82	0.53
IB2	DeRhodes	0.38	0.51	0.36	0.93		0.42
IB1	Fuller	0.50	0.62	0.32	0.51	0.73	0.32
IA1	Gale	0.70	0.38	0.66	0.86	0.52	1.17
IIA	Kellogg	0.44	0.34	0.42	0.59	0.75	0.34
IIA	Larwill	0.42	0.45	0.38	0.62	0.63	0.44
IB1	Little 1902	0.74	0.54	0.42	1.39	0.92	0.49
IIA	Little 1908	0.57	0.54	0.67	1.17	0.58	
IIB	Martin	0.59	0.39	0.29	0.81	0.90	0.59
IIB	May	0.58	0.46	0.34	0.85	1.01	1.26
IIB	Millard	0.72	0.51	0.61	0.95		
IA1	Nicholas	0.73	0.56		0.82		0.56
IA1	Roberts	0.53	0.47	0.38	1.01		0.59
IIA	Ross	0.49	0.50		0.61	0.82	0.30
IA1	Stockman	0.55	0.58		1.00		0.62
IIA	Sutton #1	0.64	0.43	0.47	0.58	0.88	0.85
IIA	Sutton #3	0.63	0.40		0.77	0.96	1.70
IA2	Waller	0.70	0.59		1.25		0.70
IB2	Walser	0.46	0.26	0.27	0.96		0.37
IA1	Ziegler	0.45	0.37		0.85	0.46	0.32
	Mean	0.60	0.47	0.44	0.95	0.80	0.67
	SD	0.17	0.09	0.16	0.28	0.21	0.36

* subtypes

Table II.21. The step interspatial depth values in Prairie houses.

ST*	House	L-D	L-K	D-K	E-L	E-D	E-K
IA1	$5000	1.69	2.72	2.51	2.62	2.07	1.59
IA1	Adams	1.90	2.95	2.14	2.33	2.71	2.95
IA2	Adams #1	1.62	2.60	2.43	2.89	2.40	3.88
IB2	Adams #2	1.46	2.51	1.93			
IA1	Baker	1.82	2.96	2.60	1.94	1.70	3.10
IB1	Baldwin	2.27	3.49	2.51			
IB2	Barnes	1.41	2.82	2.42	1.85	1.82	2.31
IB2	Brown	1.81	3.01	2.11	1.89	1.79	2.89
IB2	DeRhodes	1.43	2.75	2.36	1.8	1.8	2.83
IB1	Fuller	1.80	2.03	2.07	1.26	1.39	2.26
IA1	Gale	1.58	2.93	2.05	2.51	2.92	3.37
IIA	Kellogg	1.71	2.56	2.08	1.50	1.77	1.97
IIA	Larwill	1.80	2.73	2.15	1.97	1.63	2.64
IB1	Little 1902	1.94	4.29	2.57	1.87	2.15	4.18
IIA	Little 1908	1.65	3.35	3.20	2.62	1.77	3.92
IIB	Martin	2.02	2.89	2.16	2.03	1.73	2.95
IIB	May	1.79	2.79	2.07	2.73	2.39	3.51
IIB	Millard	2.02	2.57	2.45			
IA1	Nicholas	1.85	2.82	2.20	2.13	1.63	2.43
IA1	Roberts	1.72	2.80	2.10	2.70	1.83	2.00
IIA	Ross	1.29	2.47	2.28	1.73	1.04	2.12
IA1	Stockman	1.71	2.78	2.67	2.39	1.72	2.69
IIA	Sutton #1	1.68	2.09	2.12	2.29	2.20	2.52
IIA	Sutton #3	1.14	2.37	2.21	2.28	2.50	3.72
IA2	Waller	1.60	2.97	2.68	2.02	1.12	3.49
IB2	Walser	1.43	2.79	2.35	1.85	1.74	2.66
IA1	Ziegler	1.57	2.67	2.19	1.95	1.22	2.66
	Mean	1.69	2.80	2.32	2.11	1.88	2.90
	SD	0.24	0.42	0.27	0.39	0.47	0.65

* subtypes

Table II.22. The angular interspatial depth values in Prairie houses.

ST*	House	L-D	L-K	D-K	E-L	E-D	E-K
IA1	$5000	0.34	1.05	0.81	0.85	0.55	0.37
IA1	Adams	0.66	1.07	0.81	0.57	1.39	0.92
IA2	Adams #1	0.10	0.90	0.50	1.02	1.39	2.03
IB2	Adams #2	0.23	0.72	1.27			
IA1	Baker	0.37	0.80	1.07	0.32	0.31	1.20
IB1	Baldwin	0.46	2.37	0.78			
IB2	Barnes	0.06	1.34	0.68	0.40	0.29	0.73
IB2	Brown	0.38	1.95	0.84	0.46	0.29	1.39
IB2	DeRhodes	0.07	1.30	0.75	0.28	0.33	0.90
IB1	Fuller	0.50	0.28	0.37	0.10	0.22	0.51
IA1	Gale	0.22	0.89	0.75	0.48	1.68	1.38
IIA	Kellogg	0.29	0.68	0.34	0.18	0.19	0.36
IIA	Larwill	0.37	0.76	0.71	0.72	0.24	0.62
IB1	Little 1902	0.52	2.07	0.60	0.25	0.49	1.31
IIA	Little 1908	0.23	0.94	0.89	0.72	0.28	1.52
IIB	Martin	0.35	1.07	0.35	1.34	0.25	0.47
IIB	May	0.31	0.74	0.62	1.20	1.32	1.22
IIB	Millard	0.36	0.91	0.82			
IA1	Nicholas	0.58	1.04	0.87	0.33	0.24	0.89
IA1	Roberts	0.31	0.95	1.01	0.80	0.34	0.72
IIA	Ross	0.09	0.56	0.83	0.33	0.01	0.36
IA1	Stockman	0.37	0.88	1.26	0.82	0.39	1.05
IIA	Sutton #1	0.32	0.75	0.38	0.39	0.73	0.52
IIA	Sutton #3	0.04	0.99	0.43	1.70	1.90	1.98
IA2	Waller	0.33	1.33	1.08	0.79	0.04	1.95
IB2	Walser	0.07	1.36	0.60	0.41	0.24	0.86
IA1	Ziegler	0.21	0.85	0.85	0.24	0.06	0.65
	Mean	0.30	1.06	0.75	0.60	0.56	1.01
	SD	0.16	0.45	0.25	0.40	0.55	0.51

Table II.23. The visual depth of fireplace (F) in Prairie houses.

ST*	House	AMD_F	SMD_F	AMD_{HOL}	SMD_{HOL}	AMD_{MIN}	Diff.
IA1	$5000	0.09	1.12	0.45	1.79	0.08	2.7%
IA1	Adams	0.39	1.84	0.65	2.11	0.20	42.4%
IA2	Adams #1	0.16	1.40	0.57	1.89	0.12	8.8%
IB2	Adams #2	0.31	1.57	0.44	1.78	0.14	58.1%
IA1	Baker	0.10	1.23	0.48	1.85	0.19	-31.4%
IB1	Baldwin	0.50	1.99	0.99	2.37	0.31	28.3%
IB2	Barnes	0.47	1.78	0.44	1.75	0.16	111.5%
IB2	Brown	0.74	1.93	0.63	1.89	0.23	127.2%
IB2	DeRhodes	0.47	1.83	0.51	1.89	0.19	86.4%
IB1	Fuller	0.32	1.56	0.50	1.86	0.17	45.2%
IA1	Gale	0.22	1.49	0.57	2.02	0.16	14.6%
IIA	Kellogg	0.17	1.31	0.42	1.84	0.16	3.9%
IIA	Larwill	0.08	1.22	0.38	1.80	0.18	-49.0%
IB1	Little 1902	0.53	1.87	0.70	2.24	0.28	59.2%
IIA	Little 1908	0.33	1.68	0.68	2.24	0.23	22.3%
IIB	Martin	0.71	2.14	0.54	1.91	0.17	147.9%
IIB	May	0.47	1.85	0.56	1.93	0.24	71.7%
IIB	Millard	0.56	1.83	0.61	2.10	0.28	84.1%
IA1	Nicholas	0.07	1.22	0.55	1.94	0.13	-14.4%
IA1	Roberts	0.20	1.45	0.49	1.89	0.24	-15.7%
IIA	Ross	0.24	1.43	0.48	1.90	0.20	14.5%
IA1	Stockman	0.14	1.29	0.49	1.84	0.18	-12.8%
IIA	Sutton #1	0.46	1.67	0.51	1.90	0.21	84.2%
IIA	Sutton #3	0.59	1.73	0.61	2.07	0.24	94.1%
IA2	Waller	0.22	1.45	0.59	1.89	0.10	24.6%
IB2	Walser	0.44	1.76	0.41	1.73	0.14	110.7%
IA1	Ziegler	0.07	1.22	0.39	1.68	0.08	-3.2%
	Mean	0.34	1.59	0.54	1.93	0.19	41.3%
	SD	0.20	0.28	0.12	0.16	0.06	50.7%

* subtypes

Table II.24. Position of highly integrated axial lines (HIALs) in Prairie houses.

ST*	House	Living	Dining	Hall	Kitchen	Pantry	Entry
IA1	$5000	□					■
IA1	Adams		■	■			■
IA2	Adams #1	■	■	□	■		
IB2	Adams #2			■			
IA1	Baker		■				■
IB1	Baldwin	□	■	■			
IB2	Barnes	■	■	■	■		■
IB2	Brown	□	■	■			
IB2	DeRhodes	□	■	■			■
IB1	Fuller	■			■		
IA1	Gale	■	□	■			■
IIA	Kellogg	■	■		■	■	■
IIA	Larwill	■	■	■			
IB1	Little 1902	■	■	■		■	
IIA	Little 1908	■	■	■	■	■	
IIB	Martin		■	□			
IIB	May	□	□	■			■
IIB	Millard	■			■		
IA1	Nicholas		□		■		
IA1	Roberts		■				■
IIA	Ross	■	■		■		■
IA1	Stockman	■	■				■
IIA	Sutton #1			■	■		■
IIA	Sutton #3	□	■		■		■
IA2	Waller	■	□		□		
IB2	Walser	■	■	■	■	■	■
IA1	Ziegler	□	■	■	■	■	■
	inside (■)	48%	67%	52%	44%	19%	52%
	side (□)	22%	15%	7%	4%	0%	0%

* subtypes

Table II.25. Position of highly integrated intersections (HIX) in Prairie houses.

ST*	House	Living	Dining	Hall	Kitchen	Pantry	Entry
IA1	$5000	●**	●				●
IA1	Adams		●	●			
IA2	Adams #1		●	●			
IB2	Adams #2		●	●			
IA1	Baker						o***
IB1	Baldwin		o				
IB2	Barnes		●	●o		●	
IB2	Brown			●o			
IB2	DeRhodes		●	●o			●
IB1	Fuller	●o			o		
IA1	Gale	●	●	o			
IIA	Kellogg	o					
IIA	Larwill	●		●	●	●	●
IB1	Little 1902						●
IIA	Little 1908	●	●			●o	
IIB	Martin		●o	●			
IIB	May		●	●o		●	
IIB	Millard	●		●	●		
IA1	Nicholas	●	●				
IA1	Roberts		o				
IIA	Ross				o		
IA1	Stockman						●
IIA	Sutton #1				o		
IIA	Sutton #3		o				
IA2	Waller	●	●				
IB2	Walser		●	●o		●	
IA1	Ziegler	●	●				●
	o	7%	15%	27%	11%	4%	4%
	●	33%	52%	50%	7%	22%	26%

* subtypes
** o = between two spaces (side)
*** ● = middle of space (inside)

III. Developed tools

For the measurements in this thesis, two computational tools were designed by the author. In this appendix the properties of these tools are discussed. Hence, the first section discusses the first software, Viraph, and its results and further developments. The second section explains Dual Axial Grapher (DAG).

III.1. Viraph

Viraph (named by a combination of "visibility" and "graph") is a software package designed by the author as an alternative for some aspects of depthMap (Turner, 2001b; Varoudis, 2014) associated with visibility graph analysis. The need for this software originated from the fact that depthMap took a relatively long time to calculate the angular measures of visibility graphs on a low end computer (in some cases, hours for a medium-sized house). Hence, the author decided to develop an alternative software to reduce the calculation time. Another reason for an alternative tool was the lack of addressing step depths in depthMap (or at least in the two versions – v10 and X – which were available to the author). Eventually, interspatial depths were also added to the software. Figure III.1 shows the user interface of Viraph.

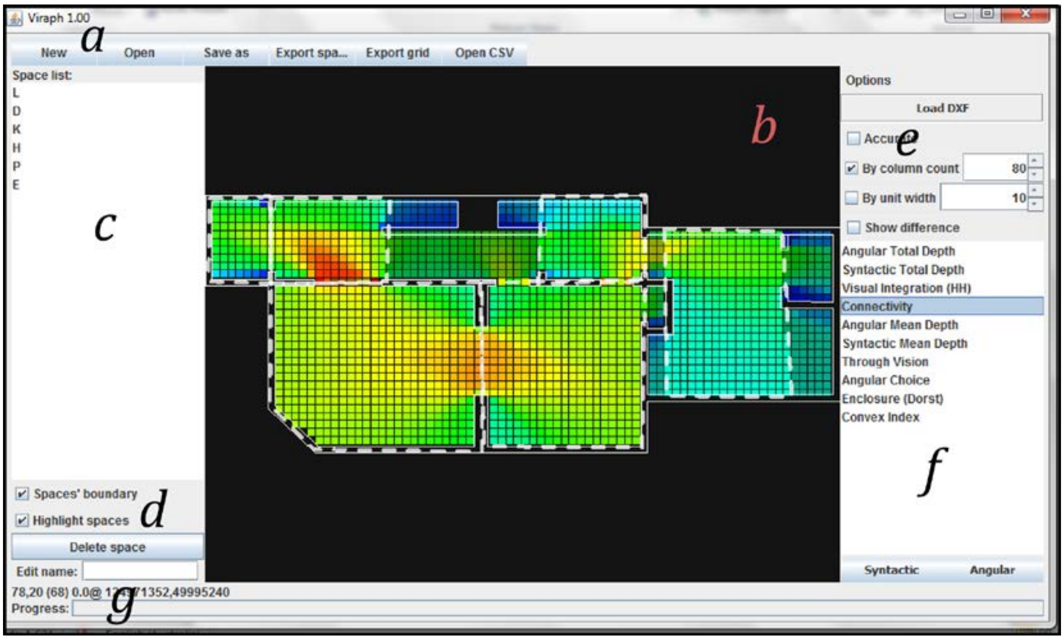


Figure III.1. A screenshot of Viraph's interface: a) main menu, b) display panel, c) list of spaces d) display option, e) grid options f) measures g) status bar.

Viraph is developed in Java language, using Eclipse IDE, within different stages between 2014 and 2015. It imports the floor plans in DXF (version R12) file formats (created in AutoCAD). It saves and re-opens graphs and results in its own file format (.*vir*) while exporting results also in forms of CSV spreadsheets or JPEG images.

III.1.1. Procedure and algorithms

The basis of the calculation of the angular depth is to divide the space into arbitrary convex areas. Considering that all points inside a convex area are visible to each other, the border between two convex areas is also mutually visible to both area. This axiom leads to two other obvious premises:

1. The shortest angular path between any two points in the respective convex areas always passes the borders between them (if there is no other convex areas in the system).
2. Therefore, the shortest path between any two points in the space will pass a number of borders between convex areas, as long as the points are not located in the same convex area (Figure III.2).

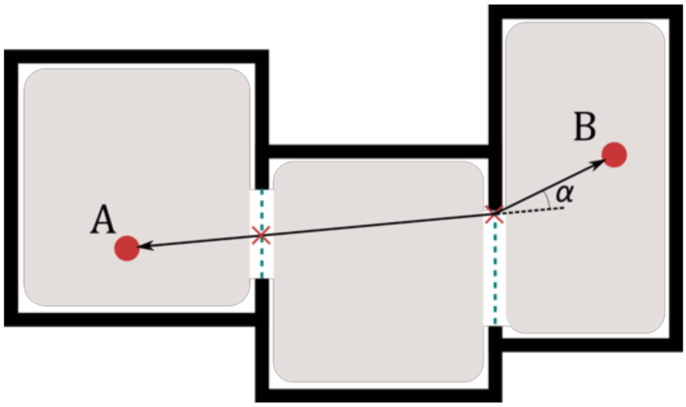


Figure III.2. The shortest path between two points (A and B) always passes through the borders (dashed lines) between the convex areas.

In other terms, we already know a number of line segments where the shortest path may pass. Furthermore, there is another fact that in a concave quadrilateral, $ABCD$, (Figure III.3), the angle δ at the concave vertex D is always larger than the angle β on its opposing convex vertex B. In Figure III.3, This indicates that the supplementary angle δ' of the larger angle (δ) will be smaller. This smaller supplementary angle (δ') is the angular depth between vertexes A and C, and so, the path $\overrightarrow{ADC}$ is the shortest path between the two points.

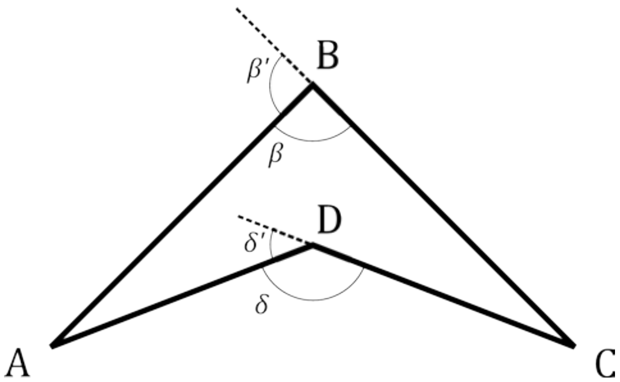


Figure III.3.

It is possible to draw similar concave quadrilaterals for any mutually invisible points in two convex areas (Figure III.4). In any case, the shortest path always passes either B or D ($\overrightarrow{ABC}$ or $\overrightarrow{ADC'}$ in Figure III.4). In other words, it is the end points of the borders between convex areas which are crucial in forming the shortest angular paths, not any other point in the middle of them. In a larger set of convex areas where the shortest path will pass multiple borders, this premise will still be applicable because that even if a segment of the shortest path passes through the middle of one or more area borders, it simply means that the two sides of that segment are inside a same virtual convex area (because they are mutually visible). Therefore, the crossed area borders are irrelevant and unnecessary to be considered.

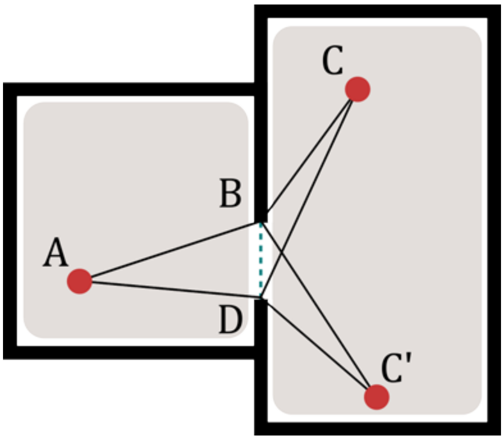


Figure III.4.

In order to find the shortest angular path between any two points, it is only necessary to recursively search the set of border end points. This is the basis of path finding algorithm in Viraph. However, this basis is only efficient when the number of convex areas are relatively small. In other terms this algorithm is only useful in buildings with fat spaces with regular convex shapes, like the cases of this thesis. Even in this case, this still maybe time consuming. Considering an a example with ten borders (twenty end point), and 4000 grid points (with only 25% mutually visible, so the shortest path of every point is sought for other 3000 other points), there are theoretically $9 \times 10^6 \times 2^{20}$ (around nine trillion) possibilities (of only full-length paths) which is still a very large number for such a simple architectural space.

Therefore, two strategies are adopted to increase the calculation speed. First, a simplification of border end points is considered by combining adjacent points (up to three neighbour grid units were combined into a single point). This strategy decreases the accuracy of but significantly increases the speed. The accuracy is more affected in acute angles. Figure III.5 shows an example of the convex area division and the endpoint combination. In this figure (b), the three convex areas make two pairs of borders with total eight border endpoints. Figure III.5.c shows a standard calculation of the shortest angular path (like depthMap) between points A and B. The angular depth value for this path is 1.57 turns or 141.0 degrees. Figure III.5.d shows this shortest path after combining the endpoints (up to 3 adjacent points are combined). The depth value in this case is 1.50 turns or 135 degrees, prompting a 4.4% difference in the results.

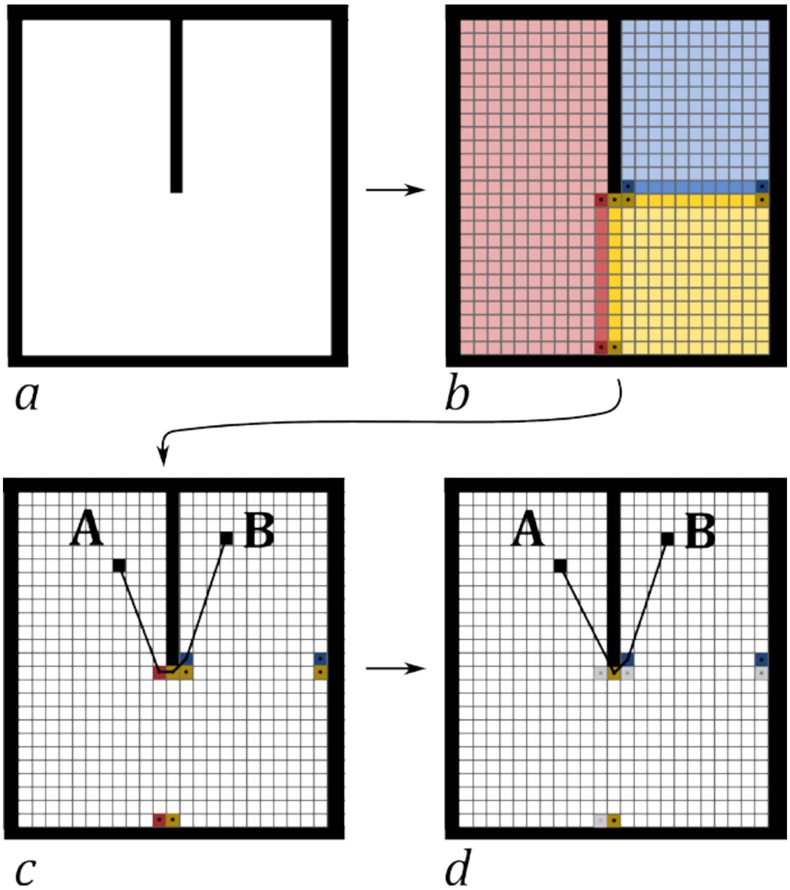


Figure III.5. an example of convex areas and border simplification: a) the floor plan, b) the convex areas with their borders and border endpoints highlighted, c) the shortest angular path between points A and B without endpoint combination, d) the path between A and B with endpoint combination.

The second strategy is the modification of search algorithm. A path is a set of line segments. In each path only two of the segments are not between the border ends. These two segment connect the two ends of the path to two border end points, respectively (or to one end point, if the path is only consisted of two segments). Thus it is possible to divide the pathfinding algorithm in two stages. The first stage finds the shortest angular paths between fixed segments attaching border end points. Subsequently, the second stage only opts the best shortest paths in the earlier stage for any two points in the space (Figure III.6). The advantage of the two-stage algorithm is that the recursive part of the search (that is the most time consuming) is done only for the lines which are tens of times less in number than the individual grid point. This strategy does not affect the accuracy of the calculation.

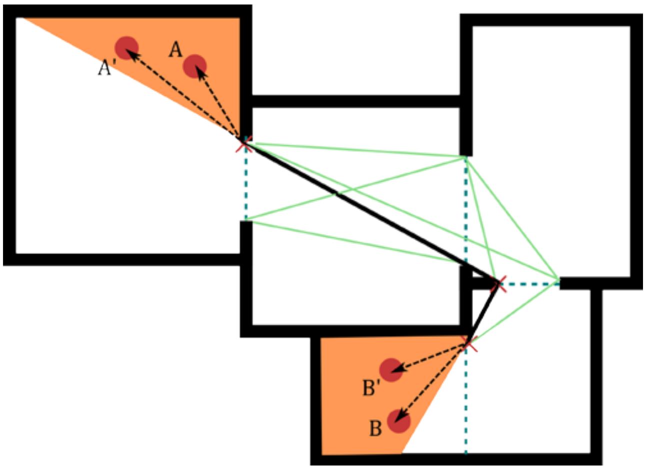


Figure III.6. By implementing the second strategy, only the angles with the dashed lines need to be measured each time for all points in the orange zones.

The following list summarises the steps of the program's calculation of the angular depths:

1. User input
    1. import the floor plan
    2. set a grid resolution
    3. set an inside point
2. Preparing the grid (by the software from this point on)
    4. detect the interior boundary
    5. articulate the floor plan into a grid based on the resolution
3. Preparing the visibility graph
    6. find which grid cells are visible to each other
    7. make the visibility graph
4. Making the convex area map
    8. find the biggest convex area around cells (after finding a convex area, all the cells inside that area are marked and the process of finding repeats for remaining unmarked cells)

9. find the border lines between the convex areas
10. find the end points (i.e. grid cells) of each border line
11. simplify the border end points by combining the neighbouring ones

5. Making the line graph
12. create a visibility graph only for the border end points
13. create a reverse variant of this visibility graph (where lines are nodes)
14. measure the angle between each pair of connected lines

6. Angular calculation
15. find the shortest path between all lines based on the recorded angles (this step is the most time-taking of the procedure), and record the starting and ending points of each path
16. for every pair of points P and Q (P≠Q) find the end of all lines which are visible to them (calling the lines visible to P and Q by two sets A_p and A_q, respectively)
17. check each member of A_p and A_q (calling them L_i and L_j) for finding the minimum sum of their angular depth (as measure in step 15), added to the angle formed by P and L_i, and the angle formed by L_j and Q (taking into mind that the end points od L_i and L_j connected to P and Q, respectively, should match the starting and ending points recorded in step 15). This minimum sum is the angular depth of the shortest path between P and Q or $D_{P,Q}$
18. add $D_{P,Q}$ to TD_P and TD_Q (total depth values of the points P and Q)
19. calculate MD_P and MD_Q by dividing the respective TD_P and TD_Q into the total number of cells in the grid

7. Interspatial depth
20. if P and Q (in step 16) are inside two different spaces (X and Y), then add $D_{P,Q}$ (obtained in step 17) to $TID_{X,Y}$ (total interspatial depth between spaces X and Y)
21. calculate the $AID_{X,Y}$ by dividing $TID_{X,Y}$ into the product of the number of grid cells in each space.

The procedure to calculate the syntactic depths is much simpler. Following the step 7 (creating the visibility graph), for each grid cell (P) the syntactic depth to all other cells (Q) is obtained by Dijkstra (1959) algorithm. The rest of operation is similar to steps 18 to 21 except that they are recorded as syntactic depths.

III.1.2. Results and accuracy

As mentioned earlier, the results of the search algorithm are affected by the simplification of the border end points. However there is another factor that contributes to a difference between the results of Viraph and depthMap. The location of the grid units are different in the two tools. This difference is up to 35% of the size of a unit in depthMap. The issue is not a matter of inaccuracy but a problem with visibility graph grids that the proper position of the units are not robustly defined. In addition, the locations in depthMap appears to be rounded in 10s (though it is not clear this rounding is only in the exported spreadsheet or applied to calculations as well).

Table III.1 shows the differences between the results of the two tools for five Prairie houses. The calculations were carried out by the same computer (a Dell Latitude 6420, with an Intel i5-2430M CPU, operating with Windows 7 Enterprise 64bit provided by the University of Newcastle under the RHD Laptop Scheme).

The results show that there is an average difference of from 4% to 6% between the results of the depthMapX and Viraph. This average difference is less than 2.5 degrees (as an accumulative angle) and under 3% of a turn. In all cases most of the differences (85%+) were under 10%. Regarding the time efficiency (in the last row of the table), the results suggest a significant increase in the calculation (at least 6 times).

Table III.1. Comparison between the results of depthMapX and Viraph.

Items		**Houses**				
		Barnes	**Millard**	**Ziegler**	**Sutton**	**Adams**
Distribution of difference (δ)	δ<1%	18.3%	19.0%	11.1%	20.8%	16.5%
	1%<δ<2%	17.2%	17.8%	9.5%	20.5%	16.0%
	2%<δ<5%	38.4%	35.5%	27.7%	33.0%	37.7%
	5%<δ10%	17.9%	19.5%	38.8%	18.8%	23.5%
	10%<δ<20%	6.3%	6.3%	11.2%	5.3%	5.5%
	δ>20%	2.1%	2.0%	1.6%	1.7%	0.9%
Difference	Mean	4.4%	4.4%	5.8%	4.1%	4.1%
	in degrees	1.7°	2.4°	2.1°	1.9°	2.4°
	in turns	1.9%	2.7%	2.3%	2.1%	2.7%
	SD	6.1%	5.9%	4.9%	5.8%	3.9%
Location difference (% of depthMapX grid unit)		31%	27%	23%	13%	35%
Calculation resolution and time						
depthMapX	total grid units	2093	2104	1753	2476	1879
	duration*	30:00**+	20:00+***	06:10	20:00+	03:15
Viraph	total grid units	2952	2602	4939	2325	3659
	duration	01:22	00:53	03:00	00:35	02:00
Viraph's minimum time efficiency (resolution^2/duration)		**×43.7**	**×34.6**	**×16.3**	**×30.2**	**×6.2**

*. depthMapX's durations exclude the preparation stage (creating the visibility graph) while for Viraph this stage is also included.
**. Time format is *mm:ss*
***. The plus sign indicates that the author cancelled the calculation at around that time. At the time of the analysis for the thesis, the author had not recorded the times, and so the times in this table are only recorded for this appendix by repeating the calculations.

III.1.3. Further development

The further steps in developing Viraph software would focus on two ways. Firstly, even if the difference between the results of the two tools is not very high, it would be possible to reduce this difference because a part of the inconsistency is related to the combined border end points. It is imaginable that a separate algorithm can accurately calculate the angular depth of dozen end points without reducing the efficiency.

The second focus will be on other emerging possibilities. For example, it is possible to use the actual convex maps of space syntax instead of the handy method used in this software. In this case, it would be interesting to combine convex and isovist mapping together. For example, the software will easily record the spaces which are visually located between two other spaces.

III.2. Dual Axial Grapher (DAG)

Dual Axial Grapher (DAG) is a computational tool developed by the author for analysing dual axial graphs. The need for developing this software was emerged from a quick survey of the popular tools of Space Syntax. The author could not find a tool for automatically devising and analysing the dual axial maps which were needed for the analysis in this thesis.

DAG imports the fewest-line axial map from depthMap (as exported screen in SVG format). Therefore, it relies on the accuracy of depthMap's axial mapping. DAG finds the intersections between the axial lines and also records the ending of the axial lines. The software then creates a dual graph with the intersections as nodes. The connection between two nodes is defined as their location on the same axial line. This graph is a simple dimensionless graph. It is easily measured by basic Graph theory algorithms like Dijkstra's (1959) which is used by DAG for this purpose. After calculating the step depth by this algorithm, the software uses standard Space Syntax formulas (Hillier and Hanson, 1984) to measure Space Syntax parameters like integration, control value, etc. DAG can import multiple files and carry the measurements for all of them in a few seconds or less, and then exporting all of the results in separate CSV spreadsheets or JPEG images.

The software offers different options of selecting end points of the axial lines as nodes, such as all or none of the end points, manually selecting them and selection by relative length. An additional option is when the end point is visible from a vertex of the boundary which is not visible from any intersection (Ostwald and Dawes, 2013).

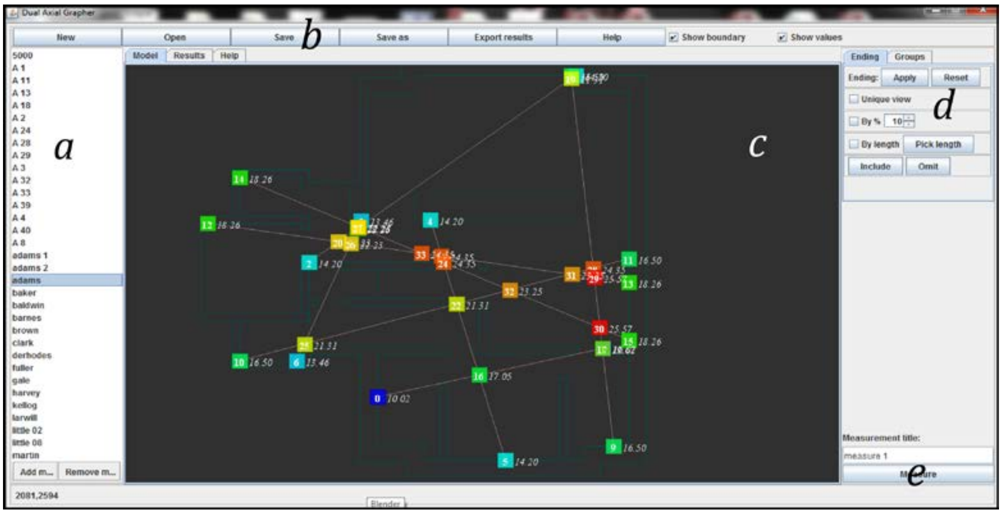


Figure III.7. A screenshot of DAG's interface: a) list of projects b) main menu, c) display panel, d) endpoint option, e) measuring.

IV. Publications

The present thesis is the outcome of a four-year PhD programme. This process has led to the devising of three related essays including two conference papers and one in-print journal article, including:

1. Behbahani, P. A., Gu, N., & Ostwald, M. (2014). Comparing the properties of different space syntax techniques or analysing interiors. In: F. Madeo and M. A. Schnabel (eds.), *Across: Architectural Research through to Practice: 48th International Conference of the Architectural Science Association 2014* (pp. 683-694) Genoa: The Architectural Science Association & Genova University Press.
2. Amini Behbahani, P., Gu, N. & Ostwald, M. (2015). Investigating the significance of wholeness in the Prairie style planning using space syntax. In: V. Popovic, A. Blackler, D. Luh, N. Nimkulat, B. Kraal & Y. Nagai (eds), *IASDR 2015 interplay proceedings* (pp. 49-61). Brisbane, Australia: IASDR Procedings Publication.
3. Amini Behbahani, P., Ostwald, M., Gu, N. (2016), A syntactical comparative analysis of the spatial properties of Prairie style and Victorian domestic architecture. *The Journal of Architecture.* 21(3), 348-374.

The first conference paper (1), presented in ASA Conference 2014, Genoa, briefly demonstrated different techniques of space syntax theory the the application with a Prairie house (the 1908 scheme for Francis Little) as a case. The second conference paper (2), presented in IASDR 2015, Brisbane, examined the claim of wholeness in the Prairie houses (with results similar to section 5.3). Finally, a significant part of the comparative analysis between the Victorian and Prairie houses was submitted as a paper (3) titled "*A syntactical comparative analysis of the spatial properties of Prairie style and Victorian domestic architecture*" and has been published in *The Journal of Architecture*. This forthcoming paper will include contains a report of the results in sections 5.2 to 5.6 as well as the developed computational tools.