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An empirical approach to the experience of architectural space

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Eine empirische Annäherung an die Wirkung architektonischen Raums

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Thesen

[Introductory theses]

Kontext.

1. Räume üben eine emotionale Wirkung auf Menschen aus.
2. Wahrnehmung und Wirkung von Architektur erscheinen tief in der Biologie und Psyche des Menschen verwurzelt. Sollten sich allgemein gültige direkte Zusammenhänge zwischen architektonischer Gestalt und Wirkung finden lassen, erscheinen diese geeignet, im architektonischen Planungsprozess als objektive Grundlage zu dienen.
3. Raumwirkung gilt jedoch im Allgemeinen als subjektiv, als deshalb kaum fassbar. Bislang besteht tatsächlich kein systematisches Wissen über die Wirkung von Räumen auf Menschen. Raumwirkung ist in der architektonischen Praxis entsprechend kein objektives Kriterium zur Beurteilung von Architektur. Eine eventuelle Berücksichtigung liegt weitgehend im persönlichen Ermessen und in der Sensibilität der Entwerfenden.
4. Während andere Planungsziele wie Stabilität, Wirtschaftlichkeit oder Funktionalität mit immer weiter entwickelten und formalisierten Methoden verfolgt werden, hat sich die Herangehensweise an Fragen der ästhetischen Wirkung über Jahrhunderte kaum verändert. Entsprechend ist es wenig verwunderlich, dass die praktische Gewichtung von ästhetischen Qualitäten im heutigen Bauprozess relativ ins Hintertreffen geraten ist.
5. Die Umweltpsychologie beschäftigt sich mit den Wechselwirkungen zwischen psychischen Prozessen und Eigenschaften der Umwelt. Entsprechend können einige dort entwickelte grundlegende Modelle auf das Phänomen Raumwirkung übertragen werden.
6. Trotz dieser Überschneidungspunkte wurde seitens der Umweltpsychologie die für die architektonische Praxis relevante Bestimmung der Wirkung

von konkreten Räumen, bzw. des Einflusses einzelner Raumeigenschaften, nur am Rande berührt. Ein Hauptgrund hierfür ist die tendentielle Fokussierung dieser Disziplin auf die Erklärung von psychischen Prozessen und individuellem Verhalten.

7. Erkenntnisse der Wahrnehmungspsychologie und Kognitionswissenschaften sowie Simulations- und Analysemethoden basierend auf heutiger Computertechnik bieten eine vielversprechende Basis, das Phänomen Raumwirkung empirisch zu untersuchen.

Ansatz.

8. Raumwirkung ist ein normales psychisches Phänomen und deshalb mit Mitteln der experimentellen Psychologie empirisch untersuchbar und quantitativ beschreibbar.

9. Vordringliches Ziel für die Architektur als praktische Disziplin muss es hierbei sein, konkret anwendbares Faktenwissen über die Zusammenhänge zwischen architektonischer Gestalt und zu erwartender Wirkung zu gewinnen.

10. Entsprechend den weitgehenden Unklarheiten bedarf die systematische Erforschung von Raumwirkung eines grundlegenden methodischen Rahmenwerks.

11. Die Grundbausteine für eine empirische Untersuchung von Raumwirkung sind eine vorläufige Arbeitsdefinition, ein grundlegendes Arbeitsmodell, die quantitative Beschreibung von Emotion und Architektur sowie eine angewandte Methodik, die es erlaubt, parallel, flexibel, kontrolliert und reproduzierbar Daten zu Raumeigenschaften und -wirkung zu erheben.

12. Trotz der weit verbreiteten Meinung, dass Raumwirkung viel zu "subjektiv" ist, um als Planungsgrundlage zu dienen, sind individuelle Unterschiede tatsächlich viel geringer als allgemein angenommen. Über wenige Personen gemittelte Daten bieten damit eine stabile Grundlage für aussagekräftige und reproduzierbare Untersuchungen.

13. Für explorative Studien, die sich eher mit der architektonischen Seite von Raumwirkung auseinandersetzen, können relativ einfache Messmethoden und Modelle für Emotion verwendet werden. Die quantitative Auswertung verbaler Beurteilungen reicht aus, tatsächliche emotionale Einflüsse annähernd zu beschreiben.

14. Der systematischen und quantitativen Beschreibung von Architektur kommt eine Schlüsselrolle für eine empirische Untersuchung architektonischer Fragestellungen zu. Ohne sie bleibt die Gültigkeit von Ergebnissen im Wesentlichen auf Einzelfallstudien beschränkt.

15. Momentan existiert noch kein allgemein anwendbares Modell zur Beschreibung von Architektur, das die psychologischen und verhaltensrelevanten Eigenschaften gezielt quantitativ erfasst.

16. Die mit virtueller Realität (VR) verbundenen Techniken und Untersuchungsumgebungen erlauben es, architektonischen Raum ökonomisch und systematisch zu variieren. Diese Technik hat damit das Potential, einen bedeutenden Beitrag zu einer empirischen faktoranalytischen Untersuchung der Wahrnehmung von Architektur zu leisten.

17. Alle bestehenden Einzeltheorien über Raumwirkung lassen sich als Arbeitshypothese auf wenige grundlegende Faktoren zurückführen.

Ergebnisse.

18. Mit Hilfe einfach zu beeinflussender Simulationsparameter können bereits heutige VR-Simulationen so eingestellt werden, dass in VR gewonnene Ergebnisse auf die Realität übertragen werden können.

19. Die Wirkung von Licht und Farbe lässt sich anhand weniger Dimensionen (hell-dunkel, warm-kalt, gedämpft-gesättigt) weitgehend beschreiben.

20. Die formale Variabilität normaler rechteckiger Räume lässt sich mit fünf oder weniger allgemeinen Faktoren bereits ausreichend erfassen.

21. Die Wirkungsqualitäten komplexer architektonischer Raumformen lassen sich anhand ihrer visuellen Eigenschaften von einzelnen Standpunkten aus gut beschreiben und vorhersagen.

22. Die Wirkung von Raumform und -farbe überlagert sich, ohne signifikant in Wechselwirkung zu treten. Allgemein erscheint die Wirkung von architektonischen Räumen als Ganzes weitgehend als Summe ihrer Teile.

23. Ein Beschreibungssystem von Architektur, das auf einfach zu erhaltenden Farb- und Geometriedaten basiert, erscheint einer auf semantischer Information aufbauenden Beschreibung für die Vorhersage von Raumwirkung gleichwertig. Beide Techniken erlauben es, mehr als die Hälfte der Varianz von Beurteilungen der Raumwirkung aufzuklären.

24. Die Wirkung von konkreten architektonischen Räumen kann nicht unabhängig von ihrem Kontext gesehen werden. Solche Kontexteffekte lassen sich jedoch ebenso quantifizieren und vorhersagen.

25. Ein allgemeines Beschreibungsmodell von Architektur für die Vorhersage von Raumwirkung sollte mindestens folgende Faktoren berücksichtigen: Generelle Farb- und Helligkeitswerte, Raumdimensionen und -proportionen, Kennwerte für relative Komplexität und Ordnung, sowie die Geschlossenheit der Raumgrenzen.

26. Architektur als akademische Richtung und Berufsfeld kann vielfältig von einer wahrnehmungspsychologischen Perspektive als Planungsgrundlage profitieren. Das Thema hat das Potential zu einem zentralen architektonischen Paradigma des 21. Jahrhunderts.

Zusammenfassung in deutscher Sprache

[Summary in German]

Räume üben eine emotionale Wirkung auf den Menschen aus. Trotz der unbestrittenen Richtigkeit dieser Aussage und ihrer offensichtlichen praktischen Relevanz für die Architektur ist das Phänomen Raumwirkung bislang wenig systematisch untersucht. Diese Arbeit nähert sich dem Problemfeld von einem architektonischen Standpunkt beginnend mit der Frage, aus welchen konkreten Raumeigenschaften auf eine zu erwartende Raumwirkung geschlossen werden kann. Da aus der vorhandenen Literatur keine ausreichend umfassenden oder empirisch gesicherten Erkenntnisse abgeleitet werden können, rückt die Erstellung und Erprobung eines grundlegenden methodischen Rahmenwerks zur empirischen Erforschung von Raumwirkung in den Mittelpunkt dieser Dissertation. Ausgehend von der Annahme, dass Raumwirkung ein normales psychisches Phänomen und deshalb mit Mitteln der experimentellen Psychologie empirisch untersuchbar und quantitativ beschreibbar ist, werden folgende Grundbausteine als erforderlich erachtet: Eine vorläufige Arbeitsdefinition, ein grundlegendes Arbeitsmodell, die quantitative Beschreibung von Emotion und Architektur sowie eine angewandte Methodik, die es erlaubt, parallel, flexibel, kontrolliert und reproduzierbar Daten zu Raumeigenschaften und -wirkung zu erheben.

Im Anschluss an diese grundsätzliche Einführung in Kapitel 1 wird in Kapitel 2 Raumwirkung von verschiedenen Seiten aus betrachtet. Es erfolgt eine Definition der zentralen Arbeitsbegriffe, das Thema wird provisorisch abgegrenzt und es wird ein vorläufiges Rahmenmodell entwickelt. Ausgehend von normativen Konzepten und Kategorien der Architektur und phänomenologischen Untersuchungen zum Sprachgebrauch wird Raumwirkung als tendentieller Einfluss einer räumlichen Umgebung auf den emotionalen Zustand eines Menschen definiert. Grundlegende auf Emotion bezogene Modelle und Taxonomien sind damit auf Raumwirkung übertragbar. Systemtheoretisch kann Raumwirkung als Funk-

tion von physiologisch-psychischen Parametern und Umweltvariablen verstanden werden. Hieraus folgt für eine empirische Untersuchung, dass unter ansonsten konstanten Bedingungen zwischen einzelnen Umwelteigenschaften und abhängigen emotionalen Variablen ein Reiz-Reaktions-Zusammenhang angenommen werden kann.

Kapitel 3 bis 5 beschäftigen sich mit den praktisch-methodischen Voraussetzungen von empirischen Untersuchungen, die auf diesem Rahmenmodell aufbauen. Sowohl Emotion wie auch architektonischer Raum müssen für vergleichende Studien quantitativ operationalisiert werden, außerdem bedarf es einer Experimentmethodik, die es erlaubt, Räume unter kontrollierten Bedingungen systematisch zu variieren.

Kapitel 3 erörtert Methoden zur näherungsweisen Quantifizierung von emotionalen Reaktionen. In der Umwelt- und Emotionspsychologie sind hierfür bereits eine ganze Reihe von introspektiven, physiologischen oder verhaltensbasierten Messmethoden entwickelt worden, doch haben umfassende vergleichende Untersuchungen ergeben, dass für angewandte explorative Studien einfache verbale Beurteilungen eine ausreichend genaue Grundlage bieten. Weiteres Thema sind individuelle und situationsbedingte Unterschiede, die für die Architektur von besonderer Bedeutung sind, da normalerweise nicht für den Einzelfall und oft für unbekannte Einzelpersonen geplant wird. Glücklicherweise haben mehrere Studien überzeugend nachgewiesen, dass individuelle Unterschiede deutlich geringer sind als allgemein angenommen, und dass deshalb bereits über wenige Individuen gemittelte Daten normalerweise ausreichen, stabile und aussagekräftige Grundtendenzen festzustellen.

Das folgende Kapitel 4 behandelt quantitative Beschreibungsmodelle für Architektur. Hauptschwierigkeit hierbei ist es, einen äußerst hochdimensionalen Parameterraum auf wenige allgemein anwendbare verhaltens- und wirkungsrelevante Dimensionen zu reduzieren, die im Idealfall auch noch gut interpretierbar sind und damit konkret im Architekturentwurf berücksichtigt werden können. Kein bestehendes Beschreibungssystem kann diesem Anspruch momentan umfassend gerecht werden, doch bieten sowohl architektonische Kompositionslehre, Raumanalyse, wie auch Wahrnehmungspsychologie und bildverarbeitende Methoden der Informatik vielfältige Ansatzpunkte, architektonische Räume nach eindeutig definierbaren Kriterien quantitativ zu beschreiben.

In Kapitel 5 schließlich werden Risiken und Chancen von Studien zur Architekturwirkung und -wahrnehmung erörtert, die auf virtueller Realität (VR) basieren. Prinzipiell scheint dieses neue Medium wie kein zweites dafür geeignet, in der empirischen Architekturforschung Verwendung zu finden, da es eine Innenperspektive vermittelt und erlaubt, Raum flexibel und parametrisch zu verändern. Jedoch kann nicht von vornherein davon ausgegangen werden, dass in VR gewonnene Ergebnisse direkt auf reale Architektur übertragbar sind. Tatsächlich vermitteln vergleichende Studien den Eindruck, dass die Wirkung von Räumen in VR ausreichend ähnlich wiedergegeben wird, jedoch die Wahrnehmung von Größen und Distanzen größeren Verzerrungen unterliegt. In mehreren explorativen Studien werden deshalb Darstellungsfaktoren untersucht, deren Manipulation geeignet erscheint, diese Abweichungen zumindest zum Teil zu korrigieren. Allgemein kann aber festgestellt werden, dass generelle Tendenzen und relative Unterschiede zwischen Räumen zuverlässig wiedergegeben werden.

An den grundlegenden methodischen Teil schliessen sich Kapitel 6 bis 8 an, die die mit der Dissertation verbundenen zentralen empirischen Studien vorstellen. Kapitel 6 rekapituliert zunächst normative Regeln sowie beschreibende und erklärende Theorien, die es erlauben, konkrete empirisch überprüfbare Hypothesen zu Zusammenhängen zwischen Raumeigenschaften und -wirkung aufzustellen und erlaubt damit einen zusammenhängenden Überblick über den theoretischen Hintergrund der zentralen Studien.

Kapitel 7 stellt vier explorative Studien ausführlich vor, die die in den vorigen Kapiteln entwickelten methodischen Grundlagen empirisch überprüfen and anhand bestehender Theorien ein breite Auswahl von für die Wirkung potentiell relevanten Raumeigenschaften erkunden. Alle vier Studien benutzen ein ähnliches experimentelles Paradigma; über mehrere Versuchspersonen gemittelte Beurteilungen von computersimulierten Räumen werden mit beschreibenden Kennwerten der Räume verglichen, die Analyse konzentriert sich auf die Feststellung signifikanter Korrelationen und damit die Identifizierung von Raumeigenschaften mit möglichem Vorhersagewert für die Raumwirkung. Die Studien 1 bis 3 basieren jeweils auf einem eigenen Beschreibungsmodell für Architektur und konzentrieren sich gleichzeitig auf unterschiedliche Gestaltungsaspekte. Studie 1 betrachtet architektonischen Raum bildbasiert, der Schwerpunkt der Analyse liegt entsprechend auf Licht und Farbe. Zusätzlich werden über Bildfrequenzanalyse gewonnene Kennwerte mit emotionalen Beurteilungen verglichen. Studie 2 benutzt ein bauteilbasiertes Beschreibungsmodell, das ähnlich einem Raumbuch insbesondere funktionale und räumliche Merkmale berücksichtigt. Um das Beschreibungsmodell zu vereinfachen, beschränkt sich die Studie ausschließlich auf normale rechteckige Formen. Deshalb liegt das Schwergewicht von Studie 3 auf der allgemeinen Erfassung und Beschreibung von räumlicher Form mit Hilfe von Isovisten (möglichen Sichtfeldern) und Sichtbarkeitsgraphen. Studie 4 schließlich vergleicht einerseits die drei Beschreibungsmodelle direkt miteinander, andererseits untersucht sie das gemeinsame Zusammenwirken mehrerer Gestaltungsaspekte beispielhaft anhand von Farbe und Raumabmessungen.

Eine vergleichende Diskussion der vier Studien erfolgt in Kapitel 8. In einer Meta-Analyse der gewonnenen Daten werden weitere generelle Faktoren (Bedeutung von Neuigkeit/Vertrautheit und Kontexteffekte) für die Raumwirkung untersucht und signifikante Einflüsse nachgewiesen. Eine direkte Gegenüberstellung der in den Studien festgestellten Raumeigenschaften mit hohem Vorhersagewert für die Raumwirkung zeigt Parallelen zwischen den Beschreibungssystemen auf und ergibt Hinweise auf wiederkehrende Faktoren. Die explorativen Studien legen nahe, dass ein allgemeines Beschreibungsmodell von Architektur für die Vorhersage von Raumwirkung folgende Faktoren berücksichtigen sollte: Generelle Farb- und Helligkeitswerte, Raumdimensionen und -proportionen, Kennwerte für relative Komplexität und Ordnung sowie die Geschlossenheit der Raumgrenzen. Eine Kombination aus bild- und isovistbasierter Analyse erscheint geeignet, diese Anforderungen zu erfüllen und hat den Vorteil, keine manuell nachbearbeiteten Daten als Grundlage zu benötigen. In Hinblick auf das provisorische Arbeitsmodell unterstützen die Ergebnisse der explorativen Studien eine grundlegende Vereinfachung: Die Annahme einer einfachen Überlagerung von gemeinsam auftretenden Faktoren erscheint im Normalfall als plausibelstes Modell für ihr Zusammenwirken.

Alles in allem unterstützen die in dieser Dissertation durchgeführten Experimente und Analysen die Grundannahme, dass Raumwirkung empirisch untersuchbar und quantitativ erfassbar ist. Die mit Hilfe der empirischen Studien entwickelten und getesteten methodischen Bausteine erscheinen geeignet, als Grundlage für eine vertiefende Forschung zu dienen. Kapitel 9 diskutiert hieraus zu ziehende Schlussfolgerungen für die vom Dissertationsthema berührten Fachrichtungen und sieht insbesondere für die Architekturtheorie und -praxis positive Chancen, die sich aus einer auf empirischen Untersuchungen beruhenden und an psychologischen Bedürfnissen orientierten Ausrichtung von architektonischen Entwürfen ergeben.

Contents

Chapter 1

Introduction

1.1 Introductory theses

Context.

1. Architectural spaces influence the human emotional state.

2. The perception and experience of architecture is deeply rooted in psychological and biological processes. Systematic relations between architectural properties and affective responses provided, this may indeed have strong implications on the architectural design process.

3. Affective qualities of architecture are however widely seen as subjective and difficult to grasp. Indeed there is no systematic knowledge on the influences of architecture on humans. Correspondingly, affective qualities are not seen as objective decision criterion in the architectural design process. Their consideration is left entirely to the personal sensitivity of the designer.

4. The classic goal of architecture of equally considering stability, functionality, and beauty has gone into imbalance mainly because of differences in the development of the respective planning processes.

5. The central concern of environmental psychology is the investigation of interdependencies of psychical states and processes, and environmental properties. Therefore, several fundamental models and approaches of this discipline are directly transferable on the investigation of affective qualities of architecture.

6. However, research in environmental psychology did not contribute much to the concrete prediction of affective qualities from architectural proper-

ties. This can be explained by a different perspective focusing on general psychical models and individual behavior.

7. Perceptual psychology, cognitive sciences as well as simulation and analysis methods based on contemporary computer technique offer a promising basis for an empirical approach to the experience of architectural space.

Approach.

8. Affective qualities of architecture are an empirically investigable and quantifiable phenomenon.
9. The primary objective from an applied architectural perspective is the generation of practically applicable factual knowledge on relations between concrete architectural properties and affective qualities.
10. Due to the almost complete lack of respective empirical knowledge, this objective demands for a fundamental methodological framework for empirical architectural research.
11. The basic elements of such a framework are a preliminary working definition, a tentative working model, quantification methods for emotion and architecture, as well as a practical empirical method that allows the acquisition of data in a flexible, controlled and reproducible manner.
12. Despite the widespread opinion that affective qualities cannot be accounted for in the architectural planning process due to their "subjectivity", individual differences in affective responses are not nearly as strong as the conventional wisdom would suggest.
13. For applied exploratory purposes, basic quantification methods of emotional responses based on introspection do sufficiently well.
14. The development of a general quantitative description system for architecture is a key issue. Otherwise empirical research is mainly restricted to case studies.
15. None of the currently existing description methods is truly comprehensively capable of describing architecture in the experientially and behaviorally most relevant dimensions.
16. Virtual reality simulations are a promising means to integrate advantages of laboratory experiments (control, flexible design, internal validity) and field studies (perceptual realism, external validity). Therefore, the can become the primary method in empirical architectural research.

17. All existing predictive partial theories on affective qualities can be tentatively related to a few underlying basic mechanisms. Yet the general picture seems to be indeed heterogenous suggesting multiple functional relations.

Results.

18. Basic easily adjustable software parameters offer a considerable general potential to improve spatial perception in VR. This allows a transfer of results obtained in VR on reality.

19. The emotional effects of light and color can be widely described by only three principal experiential dimensions (light - dark, warm - cold, muted - saturated).

20. The effective formal variance of standard rectangular indoor spaces may be already captured by five or less simple linear characteristic values.

21. The affective qualities of arbitrarily shaped architectural environments can be well approximated by describing the visual characteristics of single observation points.

22. Spatial form and color mainly superimpose each other. If there are interactions at all, they are rather secondary. Generally speaking, to a substantial degree the experience of architecture is the sum of its parts.

23. A combination of low-level descriptors predicts affective qualities of architecture as well as a model based on semantic information. Both techniques explain statistically more than half of the variance in affective appraisals.

24. The experience of individual architectural spaces cannot be seen independent from their context. Such context effects are however quantifiable as well.

25. A description system that aims at covering the major physical factors influencing the affective experience of indoor spaces should include measurands that somehow capture the overall color tone and intensity, absolute dimensions, space proportions, the degree of complexity, order patterns, and the openness of the space boundary.

26. Architectural education and practice can greatly benefit from integrating a perceptual and psychological perspective. Indeed, this approach has the potential to become a major architectural paradigm of the 21st century.

1.2 Problem statement

Architecture has an emotional impact on humans. It is a common experience that being in a dim and heavy Romanesque church feels quite different from an ordinary office space, which in turn is not the same as sitting in a cozy little restaurant. A little bit of contemplation on this, ideally within a suitable suggestive space, raises many questions. How did the builders reach these particular qualities? Did they do it deliberately, or was it just a side effect of other considerations? What are the basic constituents of these particular experiences? Do other people feel similarly here?

While immediate experience raises the truth of the initial statement beyond any doubt, it is surprising that there is so little explicit knowledge about this fundamental property of architecture. At the level of architectural education and practice, experiential qualities are seldom seen as an objective design criterion, the liability is ceded entirely to the personal sensitivity of the designer. However, from a planner's point of view, it seems natural to ask questions such as "Will people like this room?", "If they had the choice, which room would they prefer?", or "How will a particular architectural design decision affect people in that room?". Since architecture is normally built for humans and their needs, the central relevance of such questions for architectural practice is clearly obvious. And once again, it surprises that there is no somehow standardized procedure on how to integrate these questions in the architectural design process.

On the other hand, widely apart from the official academic world of western architecture, there is a flourishing subculture that seems to have readily filled a gap obviously many people experience in contemporary architecture. In recent times, particularly methods and publications using the label of traditional Chinese Feng Shui have gained considerable public attention. How to respond to such tendencies addressing apparently widespread needs as a professional or student within the western academic traditions? Neither common architectural handbooks cover such topics, at best they recapitulate few, mainly historic, normative rules on proportions or colors, nor does even detailed literature research in the related discipline of environmental psychology provide readily accessible or conclusive answers, a closer look reveals a completely different individual-centered theoretical perspective, and environment-centered practical questions are at best marginally covered in exemplary case studies.

Already the earliest preserved tract on Western architecture (Vitruvius Pollio, ca 25 BC) defines the goal of architectural design as equally considering "firmitas", "utilitas", "venustas" (stability, functionality, and beauty). The universal validity of this dictum has never been seriously doubted over numerous centuries, and, even nowadays, most architects probably agree on it. If one regards buildings from different ages synopticly, one may get the impression that the weights between these goals have gradually shifted. Even if one takes cautiously into account that currently existing buildings from earlier centuries are not a representative sample, but were subject to some form of selection process, the overall impression still remains. If the general design goals did not change fundamentally over times, one has to look for other potential explanations. Indeed, the methods for reaching stability in buildings have fundamentally changed, there is no reason to doubt the increased accuracy of contemporary methods. Also with regard to utility or economic efficiency, the planning processes nowadays are much more developed and come close to a state of quasi-science. However, with respect to beauty or aesthetic quality, the design process appears basically the same as in early times, it is still mainly a matter of intuition. It should not surprise that in present-day decision processes that aim for rationality such vague factors have fallen behind.

To summarize these initial observations, architectural spaces differ from each other with respect to certain properties which in German would be termed using the common word *Raumwirkung*, and which could be approximately translated in English as *experiential qualities*. The phenomenon itself is very common and easily corroborated by examples, but eludes from first attempts to grasp it easily. Despite obvious needs, the consideration of experiential qualities in the discipline of architecture is at best rather intuitive or normative, systematic or even scientific knowledge appears to be widely missing, and in the practical design and building process they do not play a decisive or defined role.

Are there any intrinsic reasons for this imbalanced situation? Does it reflect the actual relevance of experiential qualities? Is the apparent lack of explicit practically applicable rules just a problem of accessibility, or does it indeed mirror the state of theoretical and empirical knowledge? Are affective qualities in the end somehow inappropriate for systematic evaluation? Or has the problem just been too diverse or somehow incongruous to categories of modern science, so that it has been, let us say, overlooked?

Since none of these questions were readily answerable, even after several days of literature and internet research, the impression was nurtured that the main problem is indeed the wide lack of any well-founded systematic knowledge. This surprising white spot in the map of knowledge made it even difficult to assess to what degree findings or concepts from other disciplines such as environmental psychology are actually related and transferable.

Based on such observations, the general direction for this dissertation was born, the wish to somehow contribute to a closure of this gap. Since real-world questions arising from practical disciplines are best countered by providing a practical answer, an empirical approach was seen as a suitable means for a practically-oriented person. The complete vagueness suggested to address the big picture first. If the overall goal turned out to be too far-reaching, the approach of the problem as a whole would nevertheless either result in valuable components and solutions for partial problems or at least render novel insights into the feasibility and the general character of the problem.

Unfortunately, the academic discipline of architecture itself, commonly situated between applied engineering, arts, and humanities, widely lacks traditions and methods to address such questions empirically. Hence, the development of a suitable empirical methodology grew to a central issue itself. Yet such empirical methods required some sort of general theoretical framework in order to define goals and requirements. Therefore, it turned out that content-oriented research, the development of suitable empirical methods, and the conceptualizing of a coarse theoretical framework could only be done integratively.

1.3 Objective

The previous section has outlined several questions opening a vast field of research. Answering them comprehensively clearly goes beyond the resources of any single dissertation project. Nevertheless, before a necessary breakdown into more tractable work packages, it seems reasonable to treat the topic initially as far as possible as a coherent whole. Therefore, the dissertation aimed at conceptualizing a coarse framework as basis for further empirical research in the outlined field of experiential qualities of architecture.

Due to the exploratory character of this objective in a not yet established field of research, it seemed appropriate to approach it parallelly from multiple sides, and therefore to treat the three basic constituents theoretical framework, practical methodology, and empirical explorations as equally important and mutually dependent. The individual work packages were seen as follows:

- An exemplary proof of concept, an empirical demonstration of systematic relations between measurable properties and affective qualities of spaces, probably by a test of existing normative architectural knowledge.

- A synoptic overview on the current state of knowledge and related research. An exploration of concepts and methods from currently unrelated disciplines on their potential transferability to the scope of this project.
- A coarse provisional conceptual framework consisting of preliminary definitions, delimitations, and a working model that allows structurizing the overall goals in better tractable subquestions.
- A flexible methodology that allows an empirical test of hypotheses.
- Practically applicable quantitative operationalizations approximating affective responses.
- The development of generically applicable description systems for architectural spaces that provide comparability and capture relevant properties in simple quantitative measurands.
- First exploratory studies testing the methodology and the theoretical assumptions, and identifying likely relevant factors that have to be considered in the description systems.

The author was aware that such manifold goals would inevitably lead to a coarse patchwork with large chasms. Hence, the strategy was to make use of already existing methods, findings, and theories of other disciplines whenever possible and to transfer them on this particular topic. In particular recent developments in computer-based virtual reality simulation, machine vision, perceptual and cognitive psychology appeared to offer a promising potential to solve foreseeable methodological sticking points and to contribute to the theoretical framework.

All in all, it was hoped to demonstrate exemplarily, both by the expected findings and by the approach itself, that affective qualities of architecture are a topic open and worthwhile for empirical research. In the long run this project should contribute to an improved understanding of experiential qualities of architecture themselves, and thereby help solving practical architectural problems, but also potentially contribute to a - not yet existing - biologically or psychologically based theory of architecture.

1.4 Overview

This section describes the structure of this thesis that might in several aspects be different from others. On the one hand, the text gives an overview on the practical

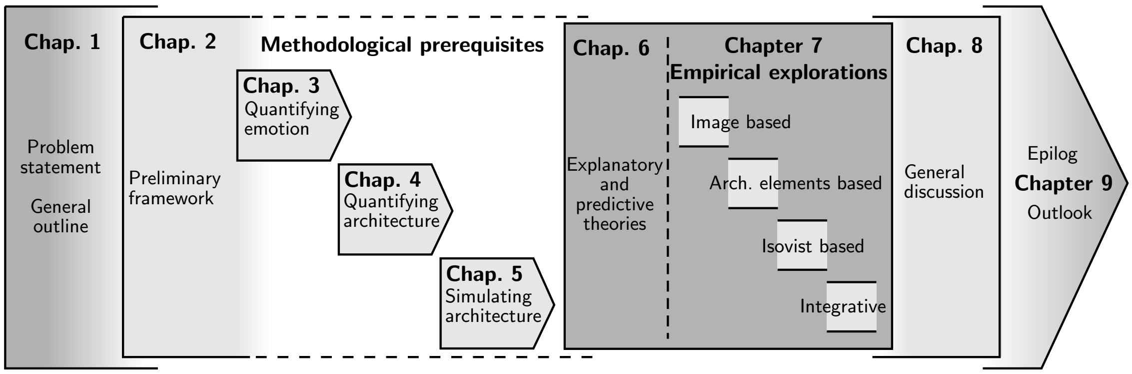


Figure 1.1: Graphical illustration of the structure of the dissertation.

empirical work that was done as central part of the dissertation project, but, as already indicated, the general conceptual design of the written thesis is fairly autonomous. In several aspects it resembles more a textbook, and in fact the author chose as a guideline to write the book "he would have liked to read about his topic". Thus, a stronger emphasis was put on the collection and synoptic report of related findings and concepts, and the book is also a summary of the current state of knowledge as basis for future research. The text is organized in thematic chapters, that themselves consists of sections that address single basic questions.

- This chapter outlines the context of the problem and explains and rationalizes the general approach of comparing physical properties with affective qualities of architectural space. Additionally, an overview on the thesis as a whole and its constituent parts is given.
- In the following Chapter 2, the main concept of affective qualities of architectural spaces is approached from several directions, its psychological and architectural background is reviewed. On these fundamentals a preliminary working definition is given, the topic is provisionally delimited, and a preliminary framework model is conceptualized. Furthermore, an overview is given on related concepts, theories, and findings.

The next three chapters are concerned with general methodological prerequisites for empirical investigations focusing on the chosen topic. Both affective experience and spatial properties have to be quantitatively described. Additionally, an experimental method is needed that provides reproducible and valid data.

- Chapter 3 discusses the issues of measuring and quantitatively describing the psychological aspect of affective qualities. Also questions concerning individual differences are touched.

- In Chapter 4, methods to describe architectural space are presented and discussed. Analogous to emotions in Chapter 3, it is aimed to describe architectural properties in a few generic meaningful quantitative dimensions. For this purpose several systems originating from architectural analysis seem useful, but equally current models from perceptual and cognitive psychology offer a potential to link both sides in a biologically plausible manner.
- Chapter 5 discusses the problem of bringing architectural space and experience together in controlled laboratory experiments. Particularly the prerequisites and potential of virtual reality simulations are considered.

The subsequent part regards the relation between the two constituents of affective qualities of spaces, the emotional and environmental side.

- Chapter 6 reviews the state of knowledge concerning relations between physical properties and affective qualities of architectural space. Both theories and empirical findings are reported.
- Based on these fundamentals developed in the Chapters 3, 4, and 5, in Chapter 7 as central part of the dissertation four empirical studies are presented that tentatively explore relations between different description systems and affective qualities covering a wide range of architectural design aspects.
- The following Chapter 8 comparatively analyzes the previous studies and discusses derivable general predications. Based on the empirical findings and their interpretation, the initial provisional framework is updated and refined.

In the final Chapter 9, the approach and the main outcomes are summarized, and the practical consequences of the empirical findings for several disciplines are discussed. Furthermore, a prospect is given on proposed directions of future research.

Since the chosen topic is situated between several disciplines, the written dissertation aims to address a diverse readership. A reader who is mainly interested in the scientific experiments and empirical findings that were the main part of the the practical work can concentrate on

- Section 2.6 that defines and delimits the core concept “affective qualities of spaces”.

- Sections 5.4, 5.5.1, 5.5.2 describe the the practical consequences resulting from the methodological approach based on virtual reality simulations
- Chapters 7 and 8 present and discuss the main exploratory studies on relations between measurable factors and affective qualities of spaces.

The theoretical framework - as incomplete as it is - is developed in the Chapters 2 and 8.

1.5 Acknowledgments

The author wants to express his thankfulness to Professor Dr. Heinrich H. Bülthoff and Professor Dr. Dirk Donath for giving the opportunity for this piece of research and their many fruitful contributions and ideas. Dr. Markus von der Heyde and Dr. Astros Chatziastros for kindly offering supervision and advice in many theoretical and methodological questions. David Zauner for his initial corrections of my incomplete English. Dr. Jan M. Wiener for his final proofreading. All my gentle colleagues at the Max Planck Institute for Biological Cybernetics for providing this wonderful environment far beyond daily work. And, of course, my family and Gabriele Hägele for their invaluable personal support.

The dissertation is partially based on studies and texts that have been published before or are currently in the process of publication (Franz, von der Heyde, & Bülthoff, 2002, 2003b, 2003a, 2004b, 2004a, 2005a; Wiener & Franz, 2005; Zdravkovic, Franz, & Bülthoff, 2005; Wiener, Rossmanith, Reichelt, & Franz, 2005; Franz & Wiener, 2005; Franz, von der Heyde, & Bülthoff, 2005b). The author thanks the co-authors for their many indirect contributions also to this thesis.

Chapter 2

What are affective qualities of architecture?

2.1 Introduction - the need of preliminary working definitions

A central aspect of empirical research is the testing of hypotheses. That means, an assumption is provisionally taking as a matter of fact, from this construct predictions are derived, the predictions are compared to reality, and the hypothesis is either approved, rejected, or updated. When exploring a novel direction of research, a basis for single hypotheses may be missing. Then several basic constituents have to be defined as well as a basic framework of their interplay. From this provisional basis, empirically testable hypotheses can be derived. Obviously, such a tentative initial framework is built on unstable ground. In the case of affective qualities, fortunately, preliminary fundamentals can be derived from various disciplines. Therefore, already existing related concepts are reviewed first. Additionally, an introductory survey (Section 2.4) collected terms suitable for expressing experiential qualities of spaces in colloquial language. Based on these fundamentals, the main concept of affective qualities is defined. Furthermore, a preliminary framework of contributing factors is introduced, primarily as basis for the following exploratory studies. Finally, further central concepts (space, architecture, environment) are briefly introduced and their specific conception for this project explained.

2.2 Approaches from architecture

The first books on architecture by far precede any beginnings of psychology as a distinct discipline, in fact the roots of architectural traditions reach much further back even in prehistoric and pre-architectural times (Canter, 2001). Consequently, early conceptions that have been partially preserved in normative architectural knowledge widely differ from more recent views at the surface level, but a closer look reveals that they are closely related to the scope of this essay. Phenomena that according to a modern view tend to be rather localized within the psyche of an individual, used to be conceived as "out there", as an objective integral part of the outside world.

Basic architectural categories. According to the theories of Canter (2001) and Valena (1994), one origin of the human interest in carefully designing architectural space has evolved from the experience of natural *places*. In all archaic cultures certain natural locations were perceived as distinctive from others, often as a place of some inherent power. Places having this very distinctive and suggestive sacred atmosphere (an almost personal *genius loci*) were initially marked by physical objects, later on these corporeal *marks* were replaced or complemented by a surrounding *demarcation*, finally the demarcation was extended and transformed into a secluded *space*, and the initially place-related experiential phenomenon was transferred on the *building*. Hence, basic for the act of creating architecture was the deliberate division of space and the corresponding attribution of meaning (in this case sacral-profane). Evidence for the outlined progressive transformation of a special natural place into a building has been provided by numerous archeological excavations at sacral building sites (e.g., see Valena, 1994).

The second basic differentiation into private inside and public outside space is seen as a close parallel to the sacral-profane distinction, because both private and sacral spaces often shared the same constituent elements and were subject to similar behavioral codes (Bollnow, 1963). Section 2.5 will show that these fundamental distinctions have partial correspondents in current models of affective experience of the environment. Thus, all three basic categories - private, public, sacral - of architectural space can be seen as early concepts closely related to the phenomenon of affective qualities.

Beauty. Also the second classic phenomenon related to affective qualities does not completely fit into modern categories of inner states and an external world. In the oldest existing textbook of western architecture (Vitruvius Pollio, ca 25 BC) beauty ("venustas") is mentioned as an architectural aim equal to stability and utility. Prerequisites for beauty are "elegant parts" and their "right proportion". This text became the base of the classic tradition of architectural literature with Alberti (1485) and Palladio (1570) as the most prominent successors. Beauty is seen as an objective property open to direct perception, but at the same time ideas from Plato and Aristotle are echoed in that the right intermediate measure reflects cosmological principles. The phenomenon of beauty has always been a central topic of philosophical discourses[1], leading to the independent discipline of aesthetics. Besides the concepts of immediate perceptual evidence and cosmological reasons (also prevalent in non-European architectural systems such as Chinese Feng Shui or Indian Vashtu, cf. Section 2.8), the standpoint of pure subjectivism (beauty is mainly in the eye of the beholder, cf., e.g., Piecha, 2004) and Neo-Platonic conceptions shall be mentioned. Mainly influenced by Plotinus and Augustinus, applied idealistic aesthetics sees aesthetic value in a consequent material realization of an initially abstract idea. This point of view plays an important role particularly in architectural design education and debate. Hence, architectural presentations often place emphasis in the idea and the process of design, and only to a lesser degree in the final result.

The core concept of affective qualities that will be defined later in Section 2.6 will integrate central aspects of beauty in the sense of "perceptual valence", as immediate emotional response mainly to the visual qualities of a stimulus. In contrast to that, aesthetic quality is seen as a deliberate or cognitive response to the formal qualities of a stimulus in accordance with an (internalized) aesthetic evaluation code. The author is aware that there is literature where these terms are used almost vice-versa (e.g., Cold, 2001, pp. 11-16), yet to his view the given distinction is more suitable, since it reflects better the use of beauty in normal language, while aesthetics is mainly a subject of scholar debates.

Place and non-place. In recent architectural debates the oppositional categories of places and non-places have become popular. For example, Anthony Vidler (1992) or Marc Augé (1994) describe the growing sense of homelessness in anonymous, flowing, passage-like spaces that have long since ousted the sheltering quality of traditional built environments. On the one hand, particularly the forms of deconstructivist architecture are seen to express or elicit these feelings. Yet on the other hand, one can also see this as a reflection of ideas and experiences parallel to Heidegger (1927, see next section), and locate its causes to a lesser degree in certain architectural languages, but rather in the lost ability of modern human beings to develop strong personal relations to certain points in space, as expressed in the word "place". The concept of place itself (cf. e.g., Manzo, 2003) puts particular emphasis on personal anecdotal, historical, symbolical, or referential meaning as sources of the emotional quality. The physical delimitation of

[1]Philosophical positions of this paragraph mainly based on Vorländer (1990a) and Vorländer (1990b).

a place can be rather vague, it is more a mental reference than a space. Although factors related to the concept of place can heavily influence the affective and experiential qualities of a particular space, they are explicitly not within the scope of this project. As regards the framework of factors to be introduced in Section 2.7, the concept of place can be seen as a superordinate term for a group of individual factors that arise from the identity, not from the physical properties of a spatial situation.

2.3 Positions from phenomenology

In his magnum opus "Time and Being" ("Sein und Zeit"), Heidegger (1927) identifies spatiality ("Räumlichkeit") as the basic disposition of human existence besides temporality. All experience and behavior is inevitably related to a spatial surrounding. Space is more than an idealized category of experience, it is a presupposition of existence and life. Mathematical space is a secondary derived idealization of intellectual aspects of life space. The relation of consciousness to the environment is completely intentional, space is the medium for actions. Despite this closest possible relation, at least the modern human being initially experiences its relation to the material world as being thrown into ("Geworfen-sein"), which implicates feelings of carelessness and needlessness. In contrast to this fundamental experience of being thrown into, in the essay "Bauen Wohnen Denken" Heidegger (1954) postulates the necessity of dwelling in space. Dwelling has to be learned and done as an active process, but finally allows the development of a positive attitude towards the world and one's own existence in it. This philosophical framework appears to be suitable for explaining individual place-related emotional responses as mentioned in the previous section, in particular with relevance to the home, but does not help much to understand the influences of particular physical structures.

In addition to this, the introduction of moods ("Stimmungen") into philosophy that substantially overlap with the concept of affective qualities can also be traced back to Heidegger (1927, p. 134). Moods phenomenologically precede the division into objects and subject. For the individual they neither reside inside nor outside of oneself, but are a constituent of the relation to one's environment. Bollnow (1963, pp. 230) particularly discusses the environment related aspect of moods and introduces the concept of tempered space ("gestimmter Raum"). He emphasizes the possible mutual influences of the introspective personal mood on the experienced atmosphere of an environment and vice versa. Furthermore, he stresses the importance of the size of available space and of colors for the emotional experience of rooms. Emotional psychology makes use of the concept of moods as well. Russell & Snodgrass (1987) use the term to denote the internal emotional state at a given time (see Section 2.5 on page 38).

2.4 An operational definition

Introduction. The experience of architectural space is not only a matter of scholar concepts, but initially something that occurs in the everyday life of normal people. Language, as a reflection of inner thoughts and states, does not depend on a priori definitions, the meaning and conception of terms arises from their practical use. Therefore, instead of directly seeking explicit definitions, a collection of statements of attributed experiential qualities seems to be a suitable way to gain a coarse overview of the bandwidth of the topic as understood by a larger quantity of people. For this reason an introductory survey on terms to describe the feeling of architectural space was conducted (cf. Franz et al., 2002).

Method. In this informal survey, 24 participants were asked to brainstorm on terms suitable to describe the character of architectural spaces. For a first group (n=18), 20 slides showing a variety of architectural spaces were presented as stimuli, but subjects were explicitly advised not to adhere to these examples. In another group (n=6), the same pictures were shown via the internet. Subjects were allowed to mix their answers freely in German or English. In the analysis the terms were collected, loosely sorted, subjectively categorized and counted to gain a coarse overview of the most common and potentially more important concepts.

Results. The total number of mentioned different adjectives was 93, and 94 different terms for evaluation criteria were referred. Table 2.1 gives an overview on the most mentioned categories and adjectives. A first subjective very cautious grouping resulted in 34 different categories that were later further subsumed to about 15-20 more distinct dimensions. There were no apparent differences between the two groups of subjects. Most subjects used a remarkably similar set of terms. However, a minority of subjects (n=2) used a noticeable different language making particularly use of complex analogies.

In a further interpretative analytical step, two different superordinate groups of terms and categories were identified. One could be termed *denotative* adjectives (e.g., “bright”, “large”), mainly referring to physical features of the scenes, the other could be labelled *connotative* adjectives mostly conveying emotional meanings (e.g., “pleasant”). But there were also transitional terms, combining emotional and descriptive qualities (e.g., “gloomy”).

Most mentioned categories		**n**
favor, disinclination	Zuneigung, Abneigung	33
dimensions, proportions	Dimensionen	28
rate of enclosure, transparency	Umschlossenheit	26
form	Form	25
level of detail, structure	Strukturierung	23
brightness, color	Helligkeit, Farbe	20
warm, cold	Wärme, Kälte	19
naturalness	Natürlichkeit	16
style	Stil	12

Most mentioned adjectives		**n**
cool, cold	kühl, kalt	10
warm	warm	9
open	offen	9
bright, sunny	hell	8
dark, gloomy	dunkel	8
cozy, homey, comfortable	gemütlich	8
friendly, pleasant, cheerful	freundlich, gefällig	7
scaring, menacing, intimidating	beängstigend	7
sterile, clean	steril, sauber	6

Table 2.1: The most mentioned adjectives and adjective categories of the introductory questionnaire characterizing architectural spaces.

Besides the existence of multiple descriptions of spaces at the same time in several scales, there was also a tendency to characterize certain indoor spaces by only one obviously unusual (mostly physical) feature. For example, some spaces were just labeled as a long, a dark or a narrow room. It seems that any physical quality can become a prevalent feature entirely dominating the experience of a room.

Related studies. Kasmar (1970) undertook comprehensive efforts to establish a lexicon of generally applicable environmental descriptors. Starting with a collection of 500 bipolar pairs of environmental descriptor adjectives, a final set of 66 dimensions was selected in various steps by criteria such as general understandability and appropriateness, unimodal distribution, and the absence of gender differences. Similarly, Hershberger & Cass (1988) conducted a more formal yet similar study and came up with 10 primary and 10 secondary dimensions of "architectural meaning", represented by pairs of opposite adjectives.

Generally, the findings of all reported studies correspond well to each other, smaller numbers of dimensions are mainly subsets of the larger ones. The differences seem to be caused on the one hand by different levels of comprehensiveness of the studies. On the other hand, Hershberger & Cass (1988) systematically evaluated interrelations using factor analysis, allowing them to reduce the number of actually different categories further.

Discussion. On the introspective level, emotional aspects seem to be an important part of the human experience of spaces. Interestingly, "subjective" emotional attributes were used the same way as more "objective" physical attributes, they seem to be equally conceived as characteristics. One could interpret this attribution as an implicit assumption of a certain intersubjectivity of experience, the emotional quality is assumed to be "out there". Yet one has to take into account that the results are not necessarily actual emotional responses, but their introspective conception. Likewise, the number of mentions of one term is mainly an indicator for its apparentness, it is only a hypothesis to assume a further correlation with importance. Furthermore, the terms presumably particularly include (possibly cultural-dependent) commonplaces that have found a definitive form of expression in language. This language dependency became particularly apparent when trying to translate and group English and German adjectives together. It was not possible to find direct correspondents for every term, sometimes they had to be either paraphrased quite cumbersomely, or translated by terms which obviously had different connotations, suggesting that the underlying concepts might also differ.

The use of adjectives denoting both physical and emotional qualities may be interpreted as reflecting naive or intuitive explanations, the actual relations can be quite different. On the other hand, these connections can be seen as common hypotheses and seem to be a suitable starting point for further empirical research.

Altogether, the analysis of language suggests that the dimensions of architectural perception and introspective experience are quite similar between humans. To what degree they also share specific experiences is subject of the later Sections 3.3 and 3.4.

2.5 Related psychological concepts

One interpretative result of the operational approach presented above was the identification of a few superordinate categories for the characterization of spaces in colloquial language. These subjective categories are similar to certain concepts of psychology and linguistics that appear very useful for a better comprehension and definition of the general phenomenon.

Denotative and connotative properties. The term denotative originates from the discipline of linguistics and signifies words that primarily convey a representational main content, while its opposite connotative comprises secondary associative meanings. For the purpose of the initial survey the term has been introduced to summarize terms that seemed directly related to certain specifiable and measurable physical properties of a spatial situation as a whole. These characterizations seem basically transferable on all rooms, yet their quantitative properties differ between individual rooms. From this perspective, one could conceive many of these terms as cognitive interpretations or qualitative expressions of percepts as relative measurements. Hence, this subgroup of terms may also be called perceptual properties.

In this context it has to be considered that perception is not just a passive reception of environmental stimuli, but an active constructive process of information pick-up and integration, thus perceptual properties are only correlated and elicited by physical properties and not necessarily direct correspondents. Furthermore, they are subject to changing environmental conditions and individual differences. This volatileness is captured in the term appearance, denoting the current elusive perception of features. Unfortunately in German the same aspect is again often translated with "Wirkung"[2].

The relations between physical and perceptual properties is the topic of an independent subdivision of experimental psychology that is called psychophysics. Its methods are briefly reviewed in Section 3.5.2.

[2]e.g., "Dieser Raum wirkt größer als der andere". In contexts that deal with both experience and appearance, it seems reasonable to prefer the verb "erscheinen".

Collative properties. Besides denotative adjectives that can be more or less concisely ascribed to particular physical features, there is a second discriminable group of words intuitively related to physics that characterize environments as a whole, but cannot be related to simply specifiable features, for example order and complexity. Going back to Berlyne (1960, 1972) and Wohlwill (1976), these so called collative properties (i.e. properties of comparison) have been defined as structural properties of a stimulus array. Collative properties have been successfully used as predictor variables for aesthetic and emotional response, and so they are a basis for several specific hypotheses (see Chapter 6). While the introspective assessment of collative properties is relatively easy, it is generally seen as difficult to directly derive them from real stimuli. There are several reasons for that, the main reason is probably that structural analysis and decomposition are in no way unambiguous. Furthermore, the definitions and delimitations of the terms complexity, diversity, entropy, legibility, clarity, coherence, simplicity, chaos, disorder, and order are rather vague or idiosyncratic. All these concepts seem to be to some degree related or contrary. And different authors apparently use different implicit concepts.

For example entropy, originally introduced as measure of physical disorder, has been transfered on information by Shannon (1948) and denotes the average amount information content within an information stream. Also the boundary value of maximum information density, the complete lack of redundancy has been called the state of entropy. This liminal state has also been called "Kolmogorov complexity", defined as the minimal amount of information to describe a system (Chaitin, 1970). Yet complexity, as the most popular yet obfuscated term has also been used to denote certain aspects of order (higher level order or structural complexity, cf. Adami, 2002).

When trying to summarize the different notions and definitions, one can do a journey from one overlapping term to another, and finally returning to the starting point. It seems that together they form a circular collative space, whose two main dimensions can be arbitrarily chosen from given oppositional pairs that themselves do not carry any overlapping meaning. It is tempting just to abstain from any further statement, yet since the topic recurs several times, Figure 2.1 tries to give an integrative overview that fits best to the author's current preliminary conception.

Emotion / affect. The group of terms of Section 2.4 that was called connotative is mainly characterized by carrying emotional content. Emotion or synonymously affect is an extremely complex and still incompletely understood psychical phenomenon that is very central for human beings and probably also for most other vertebrates. All currently existing theories and models still claim to

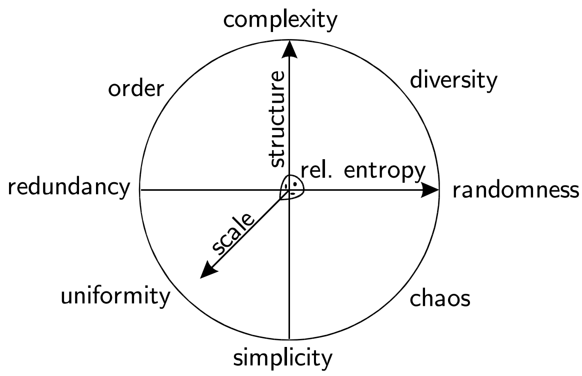


Figure 2.1: Working scheme for the relations between collative dimensions.

explain only partial aspects. One reason for that is that emotions in humans cross an epistemological border line and a philosophical main problem of psychology, the relation between introspective experience and its neurophysiological correlate. Emotions normally have physiological and introspective aspects. However, unfortunately both sides are only moderately correlated (Russell & Snodgrass, 1987), at least according to the current very incomplete state of knowledge, and it is a matter of ongoing philosophical debates whether it is theoretically possible to satisfyingly close this gap at all. Also the neuropsychology of emotions claims to be in an "infantile" state (Mlot, 1998) and could up to now only contribute to partial aspects. Hence, current models are mainly based on classical behavioral or clinical psychology, even if they focus particularly on the neurophysiological basis (cf. e.g., Damasio, 1997, 1999). So, it has to be clearly stated that, although further chapters will briefly use the terms emotion and affect, the actually used operationalizations are only a preliminary approximation to the real phenomenon.

One undisputed property of emotion is that it is a multi-dimensional phenomenon. Yet the numbers, names and relations of the dimensions differ from model to model. Early concepts described a bunch of relatively independent distinct emotions like anger, fear, excitement, or happiness. In contrast to that, system theoretic attempts integrate individual emotions in general emotional dimensions. For example, the Zürcher Model, (cf. Bischof, 1993; Schneider, 2001) uses three dimensions as inner integration variables of conceptual sensori-motor interaction loops; further emotions are basically seen as phenomenally distinct expressions of their interactions (see for example Stamps, 2000, p. 83). While at least their emergence in conscious experience can be speculatively explained as basis for complex cognitive coping strategies (cf. Schneider, 2001), no theory explains their particular feel.

If one compares several models of emotions (e.g., in Fisher, Bell, & Baum, 1984), despite their general sketchiness substantial correspondences are clearly apparent. Hence, for applied empirical investigations that do not particularly focus on the essence of emotion itself, there seems to exist a certain freedom of choice. Therefore, the following section will introduce one model a little bit in more detail. It was chosen as working basis for this dissertation project due to its simplicity and widespread use.

Systematic investigations in attitude research (Osgood, Suci, & Tannenbaum, 1957; Heise, 1970) revealed that emotional verbal evaluations contain three principal components that were termed evaluation, potency, and activity. Later Mehrabian & Russell (1974) developed a corresponding system to describe inner emotional states that used the dimensions pleasure, arousal, and dominance. This simple PAD model turned out to be generally suitable and soon became widely-used particularly in many applied environmental or architectural psychology studies.

The primary emotional dimension pleasure can be seen as correspondent to the earlier psychological concept of *valence* (e.g., in the model of Lewin, 1982, cf. Section 6.4.1). The latter term etymologically implicates that positive or negative responses can be related to underlying values which should not be understood ethically but as subjective action goals of an organism or as evaluations of the likely impact on the general well-being of an organism. Indeed, this assumed connection appears suitable to explain phenomena like unstable or bimodal responses: Since an organism most naturally has a couple of partially concurring needs and values, the same stimulus might be evaluated according to several scales. Therefore, in comparison to the other dimensions, stronger differences concerning valence within and between individuals are probable over time and context. The second dimension *arousal* is defined as a general unspecific level of activation and can be experienced as interest or excitement. It has the strongest physiological correlates, for example in the pulse rate (cf. Section 3.2). The third component *dominance* captures the feel of autonomy, subjective freedom or self-determination (cf. Section 2.2, architectural categories public-private). With respect of actions or situations it describes the level of control or the experienced availability of alternative choices. As regards objects, places, or architectural spaces, one could conceive dominance as their presence, their potential to draw attention upon them and thereby induce specific behavior (cf. Section 2.2, architectural categories sacral-private). Later investigations cast some doubts on the general relevance of dominance as affective dimension (Russell & Snodgrass, 1987), but at least the factors valence and arousal appear to be stable common denominators for describing emotion in general. Stamps (2000, p. 81) recapitulates several studies in a meta-analysis, and gets to the results that the primary factor valence accounted on average for 36% of the variance, the arousal factor about 15%, and the dominance dimension for 9%. Hence, a differentiation according to their relevance can be justified. Finally, it shall be stated that, despite their (conceptual) linear independence, the density of the three-dimensional emotional space is not uniform. For example, in real world situations an introspective differentiation between arousal and dominance is sometimes difficult. Under certain situational circumstances reliable prognoses on one dimension can be done based on others (see Section 6.4.3). Likewise, the presented preferred model is just one possible alternative. Other models that are based on rotated axes can claim the same validity (e.g., Lang's activation and interaction dimensions as alternatives to arousal and dominance, cf. Richter, 2004, p. 51).

In addition to the division into few content dimensions, Russell & Snodgrass (1987) introduced some useful clarifying distinctions of different phenomena subsumed as emotions: They defined *emotional episodes* as "classical" intensive emotions like anger or fear. Their characteristics are a correspondence of introspective experience, attributed reasons, and physiological symptoms. Furthermore, the term *mood* has been used to denote any current emotional state at a given moment in time. Finally, *affective appraisals* are attributed emotional qualities or cognitions about possible place-elicited emotions. Since affective appraisals are mainly introspective phenomena, they are not necessarily accompanied by further for example physiological symptoms. They are supposed to be particularly relevant for planning, decision making, and action. The distinction between emotional state and attributed affective appraisals can be expressed by distinguishing between pleasure and pleasingness, respectively arousal and arousingness. For dominance, an analogous word pair expressing this difference is unfortunately missing.

At the end of this section, it shall be mentioned that operational psychological concepts such as perception, emotional experience, or cognition are not independent modules, distinct sequential steps or working modes of the human brain. In fact perception, cognition, and affective evaluation are seen as parallel processes (Damasio, 1997) that depend on each other and exert mutual or unidirectional influences (Meier, Robinson, & Clore, 2004). In theories and practical research it has been proven to be useful to break down conceptually the complex psychical system into better manageable but still very broad divisions. For real world phenomena, the artificiality of such an operationalization becomes only sometimes clearly apparent, but should be always considered.

2.6 Preliminary working definition

Based on the briefly introduced fundamentals above, a working concept of the central phenomenon affective qualities which could be matched based using the German word "Raumwirkung" shall be defined. To begin with, it can be demarcated as a psychic phenomenon induced by and directed towards the environment. Due to this bidirectional character linking the individual to its environment, it may phenomenologically appear both as mental phenomenon and as property of the outside world.

As apparent in everyday language, two related yet distinguishable central aspects shall be discerned: The general comparative and the emotional. The former seems to be directly reflected in generic dimensions of introspective comparison and characterization. Table 2.2 systematizes the observations of Section 2.4 and integrates them with psychological concepts reviewed in the previous section. This more general comparative aspect shall be termed *experiential qualities* of environments. However, within these more general experiential qualities there is a central emotional core that henceforth is termed *affective qualities* of environments. For practical reasons they are provisionally equated to the three emotional main dimensions of the PAD model. Affective qualities are again a superordinate concept for two distinct aspects of emotion: On the one hand, they become apparent as already highly integrated immediate emotional evaluative responses to a stimulus, on the other hand they also comprise the prevalent *mood-altering capacity* of an environment (Russell & Snodgrass, 1987) that may not be introspectively accessible. The introspective partial aspect can also be termed as *affective experience*. Both aspects may differ significantly, but for practical reasons the following exploratory empirical studies will treat them as basically identical.

As implied in the term environment, the described phenomena are not restricted to human-built architecture, but are general for the outside world. Yet for the scope of this dissertation, the focus will be on architectural spaces. The terms are explicated further in Section 2.9. A further characteristic is expressed by the use of the word "quality", which implicates a statement about their temporal and over-individual stability. In Section 3.3 it will be discussed to what degree this assertion is appropriate.

2.7 A preliminary framework model

The overall aim of this dissertation is to contribute to the systematic investigation of relations between physical properties and affective qualities of architecture.

dimension	English adjective I	English adjective II	German adjective I	German adjective II
affective qualities				
pleasingness	pleasant beautiful	unpleasant ugly	angenehm schön	unangenehm hässlich
arousingness	arousing interesting	calming boring	anregend interessant	beruhigend langweilig
dominance	formal strict tensed controlled	unformal loose relaxed in control	formell streng angespannt fremdbestimmt	informell locker entspannt selbstbestimmt
collative properties				
novelty	novel unusual	familiar normal	neuartig ungewöhnlich	vertraut normal
order	ordered coherent clear	orderless incoherent unclear	geordnet kohärent übersichtlich	ungeordnet zusammenhanglos unübersichtlich
complexity	complex diverse ornate	simple uniform plain	komplex vielfältig überladen	einfach einheitlich schlicht
denotative properties				
spaciousness	spacious	narrow	weit	eng
brightness	bright	dark	hell	dunkel
openness	open	enclosed	offen	geschlossen
naturalness	natural	artificial	natürlich	unnatürlich

Table 2.2: A selection of main dimensions of architectural experience represented by pairs of opposite adjectives.

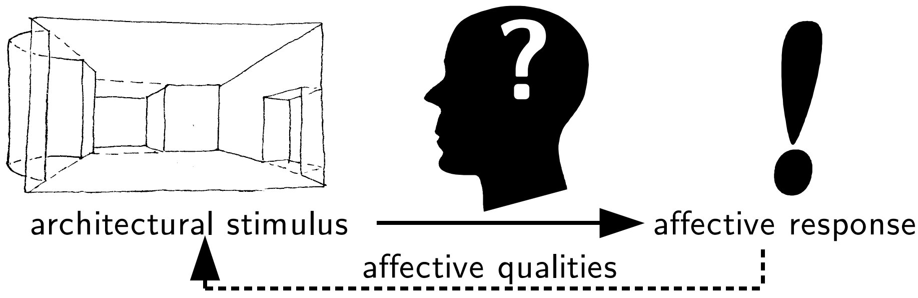


Figure 2.2: Illustration of a most basic conceptual relation between architectural properties and affective qualities.

That means, recurring patterns between a varied architectural stimulus and an overall trend in corresponding affective responses shall become quantitatively describable. If one takes it for granted that there actually are systematic relations, the simplest conceptual relation could be illustrated graphically as in Figure 2.2. This heavily simplifying potential working concept describes basically a simple stimulus-response relation that leaves however a certain openness due to the not completely defined role of the observer. An important aspect of the introduction of an observer is the implication of a relevance of the current sensory horizon. It approximates the classic paradigm of Lewin (1982, see Section 6.4.1). In analogy to Lewin's model, this basic relation could be formulated as follows:

$$affective\ response = f_{(person,\ environment)} \tag{2.1}$$

Given that the function and the inner state of the person were stable over time, a comparison of systematically varied stimuli and the corresponding affective responses would, a sufficient number of trials provided, allow the determination the inner variables and their functional relation.

Yet practically seen, this model has severe weaknesses: The entities person and environment are much too comprehensive to be used as basic constituents, and also the temporal stability of function and of the inner variables do not comply with reality. In order to arrive at tractable sizes, both a more differentiated model is required as well as a method to eliminate or consider partial terms and variables. The following formula illustrates a proposed slightly more differentiated and more flexible framework:

$$\begin{aligned} &affective\ response \\ &= f_{(predisposition,\ action\ context,\ cognitive\ context,\ perceptual\ properties,\ perceptual\ context,\ noise)} \end{aligned} \tag{2.2}$$

Both entities have been broken up and rearranged. The person is replaced by the factors individual predisposition, action, cognitive context, and the integration of perception; environment reappears as perceptual properties and context. Several aspects that the initial model included as not further specified inner variables are now explicitly considered by introducing the concept of contexts. Contexts allow the integration of environmental properties beyond the current sensory horizon as well as of definable psychical states such as action. Furthermore, they allow at least a conceptual integration of temporal aspects of perception and experience. Contexts can either be explicitly considered or excluded from a concrete study by setting them constant. The prerequisites for the latter operation are presented in Section 3.5 and Chapter 5. If these operations are applied, only predisposition, perceptual properties, and noise are left as open terms in the framework formula. Individual predispositions offer a convenient way to integrate observer-related factors that cannot be derived from the current contexts or percepts, but appear reasonable to explain individual patterns in the responses. The following Chapter 3 will discuss the method of averaging many individual responses before entering them into the actual correlation analysis in order to widely eliminate the influences of individual predisposition and random noise, leaving solely perceptual properties as main term for the comparative analysis.

Although perceptual properties, or better to say architectural properties within a given sensory horizon, are much more constricted and better definable than the initial term environment, they nevertheless cover a wide range of potentially relevant factors. A further factor reduction for a particular study can be accomplished by again setting most perceptual properties constant. Additionally, a further structurizing framework for perceptual factors of architecture would be helpful. One basis for such a framework could be the use of the concept of architectural design aspects. Using a typical strategy of problem solving (Bertel, Freksa, & Vrachliotis, 2004), most textbooks on architectural design (e.g., Krier, 1989; Ching, 1996) describe the multi-dimensional issue of architectural design by breaking it down into a limited number of to some degree independent partial problems. The following list gives an overview on typical design aspects derivable from the literature:

- position and rough shaping of the building with respect to its context
- spatial form and configuration
- spatial dimensions and proportions
- composition of architectural elements

- form and size of openings
- surface qualities: material and color
- illumination
- detailing
- furnishing

The concept of design aspects implicates that individual factors within a group are closely related and therefore best considered integratively during design and probably as well in factor-analytic studies. Vice versa, design aspects are widely independent from factors belonging to other groups. While it has to be clearly stated that the outlined framework of individual design aspects is very provisional, and clear delimitations between design aspects are in reality widely artificial, it offers at least a not completely idiosyncratic working scheme for a division of the topic into manageable entities. Additionally, the general concept may get some support by the assumption that such a categorization may reflect a way of thinking on or analyzing architecture that is shared by a majority of individuals (cf. Section 2.4). In this case the categories could have correspondences in the representation of architecture in the human mind.

In sum, although the outlined provisional framework model is also a coarse simplification, it nevertheless appears of much more practical value in its consequences than earlier concepts. While its basic elements are mainly constructs, it nevertheless allows an individual exploration of single factors or factor classes according to a specifiable basis, given that further partial terms can be successfully held constant. Therefore, the framework has several strong implications on the raising of behavioral and environmental data, which will be subject of Chapters 3 to 5, and on actual experimental design (Chapter 7). This experimental part will also allow an appraisal of the conclusiveness of this framework which will be discussed in Section 8.4.

2.8 Effects of affective qualities and their relevance

While traditional systems such as Chinese Feng Shui or Indian Vashtu Shastra take for granted that the built environment has a holistic and strong influence on the individual life as well as on whole societies, contemporary statements unfortunately seem to be rather a matter of standpoint than based on more stable grounds. The breadth of respective opinions is large. They extend from basically irrelevant, as implicitly expressed in "subjectivity", over mainly a matter of luxury (cf. the research of Kowaltowski, Mikami, Pina, Gomes Silva, Labaki, Ruschel, & de Carvalho Moreira, 2004, on wants of poor people in Brazil), to a basic factor of general human well-being and health (Cold, 2001; Ulrich, 1984). While a thorough review and discussion would by far exceed the scope of this dissertation, at least a few findings and references shall be mentioned briefly.

Generally, it is assumed that there is more than one underlying functional mechanism that might be influenced by affective qualities. Yet even the relevance of emotions itself is still also a question of debate. Opinions range from triggering atavistic archaic behavior, over the basic guidance of attention and learning (Isen, Daubman, & Nowicki, 1987; Kaplan, 1988b), to "the basic principle of cognition" (Panksepp, 1998). Regarding the relevance of introspectively experienced emotions and affective appraisals, Russell & Snodgrass (1987) stress their particular importance on long-term decision making. In addition, direct physiological, particularly long-term effects have been hypothesized. At least for some factors such as colors that are highly correlated with affective responses (cf. Section 3.2) directly measurable physiological effects have been reported (Küller, 2001). Furthermore, direct effects on spatial and social behavior have been demonstrated empirically and described as behavioral settings (Barker, 1968).

Also potential indirect effects due to social moderation shall be mentioned. Since affective qualities of architecture are likely to be associated with the inhabitants or users, effects on self esteem or on images formed on them by others have been assumed. Locasso (1988) interprets the outcomes of his replication of the seminal environmental aesthetics study by Maslow & Mintz (1956) in this way.

Finally, in industrial psychology the potential positive or negative influence of spatial forms on the quality and efficiency of working environments has at least been considered. Yet, unfortunately, investigations of the effects of work place design concentrated primarily on direct ergonomics and social structures (Frieling, 1989), and comparative long-term studies have not been carried out. Hence, design guide lines generally remain vague and do not go beyond lighting levels or color recommendations (Nemcsics, 1993). Quantitative studies can at least be found in the domain of restaurant design psychology. Robson (2002) reports restaurant seating preferences and effects of seating locations and found significant effects of architectural features on the duration of stay.

All in all, as regards the relevance of affective qualities, open questions clearly exceed the body of empirically backed knowledge. Although comprehensive studies are still missing, the majority of single findings clearly supports the assumption that affective qualities are a relevant dimension of environments and, thus, architectural design.

2.9 Definitions of further main concepts

In Section 2.6 affective qualities have been defined as object or situation directed and elicited emotional responses. Within the scope of this dissertation, the focus of interest lies on a special group of entities, subdivisions of the architectural environment. Depending on the scale or the universality of the predication, this focus is called either environment, architecture, or space. This section gives an overview on the particular conception of these terms with respect to this thesis.

Environment. The concept of environment initially comes from biology, and stresses the embeddedness and interdependency of an organism with its habitat. Perception and behavior are closely related to the characteristics of an organism's normal environment, and vice-versa, objects localized within an environment that do not have any behavioral value do not belong to it.

A direct transfer of this concept to humans can be seen as critical, because one of the characteristics of humans is their relative environmental indeterminism (Scheler, 2002). However, while their integration is probably not as complete and static as in most animals, from a less fundamental position an environmental perspective appears to be fruitful to describe and analyze many aspects of human perception and behavior integrated in its context. Since the concept of environment is very comprehensive, several disciplines concentrate on partial aspects, most notably the physical environment (focus of environmental psychology, see Section 6.4), the social environment (sociology), or the cultural context (cultural sciences, ethnology).

In this text, environment is mainly used as a general superordinate term for all kinds of settings or physical environments accessible to and experienced by humans, whether they are natural or man-made, whether they are distinctively physically defined (such as spaces) or a momentary construct of perception.

Architecture. Since this project primarily has an architectural background, but touches several further disciplines, the author sees the necessity to avoid misunderstandings and to facilitate communication on architecture by pointing out some differences in conception. Non-architects primarily conceive architecture as a general term for elaborately designed buildings. In an academic context the word is often used to express the general structural concept of a complex system (e.g., software or system architecture). Architects, however, use architecture more often as the name of their academic or professional discipline, but see it also as a process, as the act of designing a building.

Within the discipline of architecture, it is sometimes debated which factors a building requires to become "real architecture" in contrast to "mere building". Therefor often something like an intentional design beyond the purely functional is referred to. Fortunately, for the purposes of this dissertation, such subtle distinctions are not necessary. The term architecture is just used to denote the sum of buildings and to delimit them from natural environments. Several methods to describe and analyze architecture are reviewed in Chapter 4.

Space. The term space has several different meanings, depending on the context or discipline: There is, for example, Euclidean mathematical space, finite physical space, and often a distinction is made to the experienced space of psychology or phenomenology. In architecture, spaces as aggregate term are discerned from space, denoting the abstract category. In contrast to the related concept of places (cf Section 2.2), spaces are primarily defined by their physical structure, implicating extension and more or less defined boundaries. In this thesis, space will be chiefly used as a collective term for the plurality of spatial situations in built environments. This conception is similar to its use in everyday language, and could be equated approximately with perceptual space. While the following investigations of relations between affective and physical qualities will be carried out within the framework of spaces, this attribution is partially mainly conceptual, since the analyzed properties in some cases solely relate to certain particular places within these spaces.

2.10 Summing up

Experiential qualities can be coarsely described as psychological phenomena directed to and elicited by the architectural environment. They comprise affective qualities that are defined as the potential to elicit emotional response to architectural environments, including conscious affective appraisals and possibly subconscious mood altering effects.

The current state of knowledge allows the description of a distinguishable field of research which touches several traditional disciplines. Despite many partial theories, it is still in an early pre-paradigmatic state. The overall vagueness does not hinder empirical research on actual relations between physical properties and affective responses, in fact this aggregation of factual knowledge appears as a promising operational approach towards a better understanding and delimitation of the core concepts. Accordingly, the following chapters will present further prerequisites necessary for an exploratory approach.

Chapter 3

Quantifying affective qualities

3.1 Overview

As one outcome of the previous chapter, the central concept initially termed Raumwirkung was defined as affective qualities of architectural environments. This chapter now discusses one central prerequisite of an empirical approach, the empirical quantification of such affective qualities. In the following section, several techniques to measure individual affective responses will be reviewed. For making the overall goal of identifying physical correlates feasible, these responses need to possess a considerable level of stability, over time as well as over individuals. Hence, Section 3.3 will discuss whether the usage of the term affective qualities is really appropriate. Additionally, Section 3.4 gives a brief overview on findings of differential psychology regarding individual differences in the experience of architectural spaces. Finally, Section 3.5 discusses the pros and cons of the two main data raising procedures, the field study and the laboratory experiment.

3.2 Measuring emotional responses

As outlined in Section 2.6, there are good reasons to discern two complementary aspects of emotion: the introspective-phenomenal, only accessible by the experiencing individual and the neuro-physiological, behavioral, observable. Since it is principally doubtful to capture emotions sufficiently by regarding only one side, ideally studies should consider both aspects of affect parallelly. In the following, established quantification methods of experimental psychology shall be briefly reviewed.

Verbal techniques. For getting insights into the introspective aspect of emotion, a straightforward method is making use of the way adult people normally communicate their feelings, by verbal statements. Based on self reports, several data raising methods have been introduced (for an overview see Bechtel, 1987).

For quantifying the three principal dimensions of affective appraisals as described in Section 2.5, Mehrabian & Russell (1974) developed a verbal scaling technique that basically was a specialized form of the well known *semantic differential* from attitude research (Osgood et al., 1957; Heise, 1970). In a semantic differential, dimensions of environmental qualities are represented by pairs of oppositional adjectives (e.g., cf. Table 2.2) and a rating scale (usually seven discrete steps) in order to allow a differentiation between the two extremes. A similar technique is the use of *word lists*. Here subjects just select a subset of words from a given set that fits to a particular situation. The techniques of word lists and the semantic differential for measuring attitudes to architectural settings are relatively popular since the late 1960s in environmental studies. In particular the semantic differential has been used in many classical environmental psychology studies (e.g., Kasmar, 1970).

Furthermore, *similarity scaling techniques* have sometimes been been used (e.g., Hershberger, 1988; Oostendorp & Berlyne, 1988). Together with multi-dimensional scaling analysis, they allow an exploration of the dimensionality of a phenomenon, and may provide insights in the relative weighting of different dimensions. While similarity ratings have the advantage of not imposing any criteria externally, they however suffer from the drawbacks that the meaning of the computed dimensions is often difficult to interpret.

Stamps (2000, pp. 98-101) has done a meta-analysis on a major number of studies using more than one scaling technique, also comprising unusual techniques such as *pairwise forced-choice* comparisons. He found a reliable and extraordinarily high level of intercorrelations between the various techniques (collective correlation r=.99) that led him to the conclusion that all common introspective scaling methods are basically equivalent, and parsimony suggests to take the most simple semantic differential.

All these methodological approaches based on introspection and self-reports have been often criticized due to their potential obtrusiveness and dependence on language categories (e.g., Craik & Feimer, 1987). Russell & Snodgrass (1987) however could show that the general results of self reports substantially correspond to other data raising techniques, and due to the lack of real differentiating alternatives, these verbal techniques often still appear most reasonable. Nevertheless, some studies also clearly show the limitations of verbal techniques. Russell &

Snodgrass (1987) report a study by Winslow & Herrington (1936) that found subliminal effects of odor subjects were not aware not, but had significant behavioral an probably mood-altering effects. Hence, Russell (1988) only assumes a close relation between the actual mood altering capacity and the introspectively evaluated quality of environments, but leaves space for a certain autonomy of different methods and measures.

Behavioral indicators. *Facial expressions* are the classic characteristic concomitant of emotions, they are seen as closely linked to real emotional episodes like fear, anger, or disgust. However, these "hot" emotions are seldom elicited by the built environment, affective appraisals or mood changes are not reliably accompanied by distinct facial expressions, hence, they do not appear to be reliable indicators for emotional responses to environments.

Bechtel (1970) has introduced the observation technique of *behavioral mapping* that basically means to record humans' (spatial) behavior in relation to their spatial environment. The technique has been used to measure proxemic effects on social behavior (Canter, 1973; Christl & Richter, 2004), and it is obviously transferable on interactions with the physical environment. It has been also used as a sort of small scale rating method (Kim & Branzell, 1995). Manually assessed behavioral mapping has been successfully applied in clinical studies. For example, Alzheimer patients show a set of easily recognizable distinct behaviors that can be systematically recorded and compared to environmental features (La Garce, 2004).

Since spatial behavior and experience are obviously not directly connected, behavioral maps are unfortunately often difficult to interpret. A general problem is the wide range of variability in spatial behavior, potential influences of the environment are superimposed by a lot of non-architectural (e.g., temporal, social) or trivial factors such as hard spatial constraints. Yet on the other hand, the big advantages of behavioral maps are their ecological validity and unobtrusiveness. The method seems to be particularly suitable to be combined with virtual reality simulations (cf. Chapter 5), because this medium allows the recording of spatial behavior at virtually no effort. Here, however, the experimental task has to be carefully chosen and also influences of the setup and interaction device have to be considered.

In a small pilot study done by Jan M. Wiener and the author, exploration behavior in a virtual labyrinth was compared to the spatial structure of environments (See Figure 3.1). Several hypotheses were raised on likely route selection behavior depending on the spatial form visible at decision points (e.g., preferences for larger over smaller rooms, preference for a diverse spatial profile over an unstructured

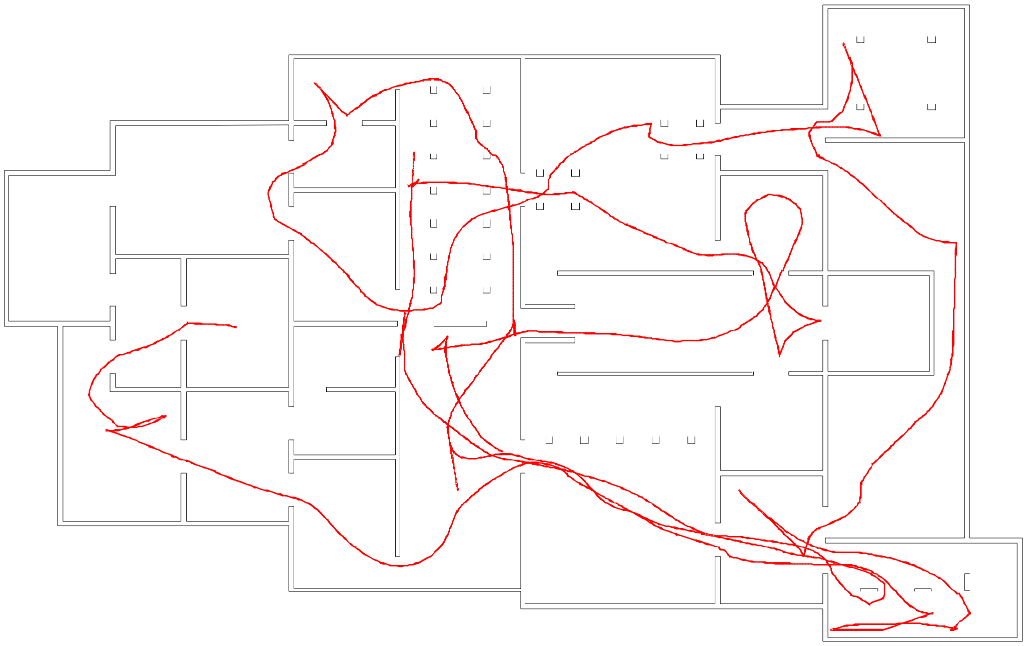


Figure 3.1: Example trajectory of one participant from a behavioral experiment in a virtual maze. The participants had to find five objects that were hidden in a gallery like virtual space.

room, and preferences for obvious continuations). Taken all hypotheses and samples together, the recorded behavior was in accordance with the hypotheses (Chi square test p=0.05). However, the small number of measured values that were obtainable from free exploration turned out to be a major methodological problem, since only first time decisions and entries from the correct direction could be used. Furthermore, in this case study influences of the global room layout and configuration were not separable from local effects. So, while generally promising, for being practically useful, the method currently lacks elaborate experimental designs and analysis methods (for further improvements of the analysis technique refer to Wiener et al., 2005).

A further behavioral method is the measuring of environmental *influences on subjects' performance* in experimental tasks needing concentration and attention (Stone, 2001). For example, Shibata & Suzuki (2004) have used a Stroop test to determine influences of plants in working environments. Oberzaucher (2001) did similar studies using driving licence tests. Although it can be assumed that performance is correlated with positive valence and an "optimal" arousal level, a direct transfer on affective qualities is however difficult.

Finally, a comparison between *response times* and ratings in a factor analytic study of the author (see Section 7.3) revealed correlations between the ratings and the extremity of judgments. That means that the larger the absolute distance of the rating from the scale mean, the shorter the response time (0.12 < correlation coefficient $r < 0.25$, $0.001 < p < 0.05$). Yet, due to the small proportion of explained variance ($r^2 < 0.06$), this behavioral measure turned out to be not practically relevant.

Physiological measurands. In emotional psychology and psycho-pathology several physiological measurands are used to test for affective responses. All classic methods measure correlates to the emotional dimension of arousal. Typical indicators for heightened arousal are accelerated heart rate, lowered skin resistance, heightened body surface temperature, and an increased pupil diameter. A further more sophisticated method is the electro-encephalographic (EEG) recording of brain activities. Two components of the waking brain signal referred to as Alpha and Delta signal are reported to be highly responsive to environmental stimulation (Küller, 2001). When a person is relaxed, Delta and Alpha waves are clearly detectable, but stimulations by light changes and noise effectively attenuate them. This general brain activity seems to be triggered by a region called reticular activation system.

Physiological correlates have the advantage of being much less cognitively penetrable and influenceable than self reports. Furthermore, they may be less obtrusive and interfering with experimental tasks and offer a higher temporal and discriminatory resolution. Yet, beside the initially stated limitation to arousal, there are some further general drawbacks. First, to be reliably measurable, most physiological indicators need an intensive level of involvement of the test person, corresponding to a real emotional episode in the framework of Russell & Snodgrass (1987). This is however seldom reached in experiments with non-phobic participants. Normally a deliberate affective appraisal is not accompanied by the required level of arousal. Furthermore, according to Russell & Snodgrass (1987), only moderate correlations between these indicators and introspective experience were found.

Besides behavioral observations and the classic physiological measurands described above, the knowledge on functional processes involved in emotional responses at the neuro-physiological level was initially mainly based on lesion studies and invasive animal experiments (for an overview see, for example, Kandel, Schwartz, & Jessen, 1991, pp. 982-997). In recent years methods such as functional magnetic resonance imaging (fMRI) offer non-invasive alternatives to associate mental events and processes with activity in brain areas. The basic paradigm of fMRI says that neural activity is correlated with increased blood flow in the involved brain areas. The influence of this flow on the magnetic field can be measured. If the brain areas were known that are involved in emotional responses, such imaging techniques would offer the possibility to detect or measure emotional responses very directly. Indeed, various studies (e.g., Lang, Bradley, Fitzsimmons, Cuthbert, Scott, Moulder, & Nangia, 1998; Beauregard, Levesque, & Bourgouin, 2001; Oya, Kawasaki, Howard, & Adolphs, 2002) have found that experienced arousal is correlated with the general neuronal activation level in several areas, depending on the kind of stimulus, a finding that is in accordance with the theoretical framework of Berlyne (1960, 1972). In particular the limbic system including the amygdala seems to play a central role in real emotional episodes (Morris, Frith, Perrett, Rowland, Young, Calder, & Dolan, 1996; Birbaumer, Grodd, Diedrich, Klose, Erb, Lotze, Schneider, Weiss, & Flor, 1998). Even affective appraisals might be correlated to identifiable local neural activity (Erk, Spitzer, Wunderlich, Galley, & Walter, 2002). All in all, modern neural imaging methods offer a great potential also for emotional research. The necessary effort however is currently immense, and the experimental setup is very inflexible and obtrusive. Furthermore, the exact attribution of activities to emotion in contrast to for example perception and recognition processes has still to be treated with reserve, since a strong stimulus dependency can be observed.

3.3 Affective responses versus affective qualities

The previous section has presented several methods to quantify approximately single affective responses, which are related, but not identical to the central concept affective qualities as introduced in Section 2.6. As all psychical phenomena, affective responses are subject of individual and situational variations influenced by several physical and non-physical factors (the current state of knowledge on the latter will be presented in the following sections). For systematically investigating the proportion of variance in affective responses that was caused by physical properties of the environment, individual affective responses do not offer the necessary stability for meaningful correlation studies. Therefore, in this section the relation of affective responses and the concept of affective qualities is discussed in more detail.

The basic supposition underlying the concept of affective qualities is the existence of stable tendencies in affective responses to environments despite of individual and situational differences. If this holds true, individual affective responses can be summarized and their distribution statistically described. A central paradigm of statistical theory and social psychology says that phenomena whose individual appearance is subjected to multifactorial causation tend to be normally distributed (cf. e.g., Gleitman, 1994; Bortz, 1999, pp. 74-79). One theoretical explanation of this often observable distribution is to conceive individual and situational differences as many linearly independent additive factors. In this case standard terms such as mean and standard deviation values can be used to completely characterize the tendential emotional effect in the same dimensions as the underlying individual data. Fortunately, the literature provides conclusive evidence that affective responses actually follow statistically the outlined pattern (cf. also Section 8.4). Numerous studies have directly or indirectly addressed this issue (e.g., Kasmar, 1970; Mehrabian & Russell, 1974; Hoffmann, 1976), and a comprehensive meta-analysis of Stamps (2000, pp. 114-139) has revealed and quantified a dominant "sensus communis" over studies from 21 countries covering various demographic groups. Furthermore, Russell (1988) points out that eight individuals or even few normally suffice to get reliable and stable mean values, provided that the sample is not based on certain identified special groups of participants (see Section 3.4).

Besides doubting the level of consensus, the validity of the concept of affective qualities can be questioned by assuming a dominant influence of the situational context. In this case, observable common trends between individuals would be mainly caused by the experiment or survey, but would not mirror actual environmental influences. Due to the lack of completely unobtrusive studies, this objection cannot be rejected by currently existing empirical data. Nevertheless, several plausible arguments can be raised against this hypothesis:

- A comparison of studies using different data raising and survey techniques (see Section 3.2) reveals substantial similarities.
- Introspectively, affective appraisals are experienced as properties of the outside world. It is common every day practice and often successful to transfer personal experiences as first approximation on others.
- Emotional assessments of the outside world independent from a current task is biologically plausible and reasonable, since organisms are often in an "exploration mode" (cf. diversive behavior, Wohlwill, 1976), that basically is a prospective assessment of potentially useful or harmful environmental properties.
- Several explanatory theories for emotional responses to environments offer plausible explanations for action-independent tendencies (see Chapter 6).

It seems therefore a reasonable working assumption to attribute the existing common tendencies in empirical data to influences of certain environments.

In sum, despite the widespread opinion that affective qualities cannot be accounted for in the architectural planning process due to their "subjectivity", empirical investigations come to a different result. Individual differences in affective responses are, statistically seen, not nearly as strong as the conventional wisdom would suggest and therefore justify the introduction of affective qualities as construct denoting the prevailing mood altering tendency. Following a common practice of environmental, differential, and social psychology, consensus among a group of judges or observations is used to establish a property that is conceptually attributed to the object judged. This operative concept mirrors the introspective experience of environments that initially does not clearly divide between physical properties and psychological effects (see Sections 2.3 and 2.4). Also it meets the environment-centered perspective of architects and planners that rather concentrate on the entities of their designs than on the inner perspective of later users. Moreover, later users are often not yet personally known during the design phase, or buildings are planned to be experienced by many people, thus a consideration of individual responses is neither possible nor desirable. Here affective qualities offer the possibility to integrate psychological responses or needs in the planning or decision process.

3.4 Non-physical factors affecting emotional responses

In the previous section empirical findings have been presented to argue for a conceptual and analytical attribution of affective qualities to the stimuli. Yet, of course, affective responses are initially singular events, hence, subject to individual and context-dependent differences (cf. Section 2.7). Besides the physical factors that are core of this dissertation and are treated in the Chapters 6, 7, and 8, several studies investigated non-physical factors in order to explain the observable variance further by ascribing it to individual properties of the subject. While not themselves at the core of this dissertation, they are briefly reviewed in the following sections because of their explanatory value and their relevance for the design of empirical studies, for instance for the selection of participants. A careful balancing and the acquisition of respective personal data offers means to enhance the external validity of studies or to reduce the number of required subjects.

Demographic factors. Stamps (2000, pp. 114-134) summarizes several studies analyzing the influence of demographic factors and presents detailed correlation coefficients between samples drawn from different demographic groups (e.g, country, gender, education, profession). He concludes that demographic effects in environmental preferences are not nearly as strong as often assumed. Only the factors children vs. adults, designers vs. non-designers, and interest-groups vs. the general public turned out to be relatively important and to exceed the overall common proportion of variance r^2 of 0.67, particularly for very modern and stylish buildings.

Cultural dependency. It is an ongoing debate to what degree this substantial level of accordance between humans from all over the world (Nasar, 1988c; Stamps, 2000, pp. 114-134) is caused by hard biological factors, or just a consequence of world-wide cultural levelling. A typical argument against biological explanations is the large variety of traditional building and housing forms. A classic intercultural comparison on the origins of these differences (Rapoport, 1969; Eckensberger, 1976) suggested that natural conditions coarsely define the bandwidth of possible forms, yet the actual formal occurrence is mainly culturally dependent. Yet, as Weber (1995, pp. 61-62) points out that the basic processes of perception are identical, and also the dimensions (Heise, 2001) are the same across cultures. Houses normally have a strong cultural meaning and value, but are at the same time a typical archetype. Hence, it is probable that both collective as cultural aspects contribute to the overall experience.

Personality dimensions affecting environmental preferences. Yik and Russell (2001) have shown substantial correlations between a person's actual mood and her or his personality traits. Hence, one can assume that also affective appraisals of environments are influenced by the individual emotional predisposition. Beyond such general connections, several studies (Mehrabian & Russell, 1974; Mehrabian, 1978; Russell & Snodgrass, 1987) have concentrated on more specifically environment related traits. Two character traits turned out to be related to spatial behavior: arousability and arousal-seeking tendency. While the former likely affects the intensity of emotional arousal induced by the environment, the latter should allow refinements for the predication of pleasure based on the level of arousal (see Section 6.4.3).

Situational parameters. Affective responses and probably even more affective appraisals are influenced by the current intention or action. Based on the ecological action theory (see Section 6.4.1), one can assume that particularly responses in the valence dimension are influenced by an environment's usefulness or obstructiveness with respect to the particular action context. Related to action, in post-experiment interviews ensuing the exploratory studies of this dissertation (see Chapter 7), several participants reported that their appraisals had been different if the actual function of the assessed rooms would have been specified. The function and functionality concept certainly reflects the idea of suitability for certain actions.

Further specific predications and empirical studies are rare, maybe because the concepts of action or plan are generally difficult to systematize and compare. The question of the influence of situational parameters is however central for assessing the validity of different experimental methods which will be discussed in the following section.

3.5 Data raising procedures

3.5.1 Field studies versus laboratory experiments

Experiences in the test tube - the question of validity. As mentioned in Section 3.3, the validity of studies that are interested in normal real world responses or behavior, but interfere with the situation, can be questioned. Particularly studies based on verbal self-reports introduce a forced focus on introspection that is not normal in everyday life. Additionally, differences between the introspective and the reported attitude are always possible, although in the context of environmental assessment there are less obvious motivations for doing so than for other, more controversial, topics. Similarly, completely "natural" spatial behavior under known observation is not realistic. On the other hand, the task "evaluating environmental situations" itself is biologically plausible, because diversive exploratory behavior certainly also serves the memorization of potentially promising places. Also several normal human actions resemble experiments' situational context, e.g., house-hunting, the decision for particular seats in pubs or cafes (Robson, 2002), or the selection of resort domiciles, supporting the ecological validity of experimental appraisal tasks.

So, on a less fundamental level, it is a serious and open question which data raising procedure offers the best mixture of control, flexibility, validity, and effort for a particular scientific question.

Discussion. The topic that is briefly reviewed here has a long tradition in the methodological discussions of experimental psychology (cf. e.g., Stapf, 1976; Kaminski, 1976). Particularly initially environmental psychology partially defined itself by a methodical approach depending mainly on observations in situ (e.g., prominently Barker, 1968). Nowadays, instead of a decision between either field studies or laboratory experiments, the debate has widely settled, and both approaches are rather seen as complementary, both possess specific advantages and disadvantages.

Generally, laboratory experiments normally increase their internal validity at the cost of the external, while field studies tendentially weight these factors vice versa. In laboratory experiments the situational context is normally much more artificial, the general interferences by observation and the artificiality of actions in surveys and experiments are much higher. On the other hand, they normally require much smaller sample sizes, take less time, and can render more exact quantitative data. The better level of control also facilitates the detection of smaller effects, that otherwise would not feature reliable contrast against the higher noise level. The two methods also differ in their potential to consider temporal aspects of observable phenomena. Laboratory experiments can only observe immediate or short-term effects, since, aside from practical issues, prolonged experiments would probably render meaningless results due to their unnatural context. Although, on the other hand, field studies may theoretically allow for an observation of naturally occurring long-term effects, the interference of changing conditions cannot ruled out easily. Therefore, reliable data on long term effects are almost completely missing.

Besides these principal considerations, also several empirical studies compared the two approaches. Generally, the actual differences between data gained in the laboratory and in situ was rather small, provided that the laboratory experiments used appropriate stimuli (see Section 5.2). The consideration and quantification of context effects (Russell, 1988) as control variables has turned out to be secondary in practice. For example, Stamps (2002, 2003), could not find significant effects of different environmental conditions (time of day, presentation room, viewing distance, ambient light levels, presentation times) on environmental assessments, factors that might be relevant for both laboratory experiments and field studies.

All in all, field studies are rather seen as advantageous for exploratory research generating hypotheses, while laboratory experiment are tendentially more suitable for the test of hypotheses. Yet for a concrete empirical question the actual relevance of the principle advantages and drawbacks of each approach have to be appreciated individually. Besides rationalizing a decision, this consideration process might also render useful insights on how to actually design an experiment to optimize its general validity.

3.5.2 Psychophysical laboratory experiments

Within the various directions of experimental psychology, psychophysics represents the extreme contraposition in contrast to unobtrusive passive real-world observations. Uncompromisingly, in classical psychophysics control, reproducibility, and quantitative methods have been extended at the expense of naturalness. Typical characteristics are a consequent stimulus reduction in perceptual experiments under completely constant laboratory conditions and the systematic, balanced, and independent variation of stimulus properties which normally leads to a huge number many of repetitive trials and small numbers of participants. Psychophysicists can base there studies on a well-established theoretical framework going back on Fechner (1876), there are quantitative methods to compare normally incommensurable data, for example by their just-noticeable differences

(JND), or by active stimulus adjustment. A further overview on the psychophysical methodology can be found in several textbooks, for example Gescheider (1997).

3.6 Summing up

Although affective responses are primarily individual, a substantial and overall dominant proportion of communality has been proven in many empirical studies. Due to that reason the term "affective qualities", implicating external attribution, can be justified. In this concept individual differences and situational factors are provisionally excluded. Apart from that, several personal factors have been identified that are systematically correlated with deviations from mean responses. In principle, their consideration as control variables allows a further refinement of data raising techniques, particular in smaller samples.

While verbal scaling techniques have often been criticized, for the current still pre-paradigmatic and preliminary stage of concepts and models they have turned out to offer the same capabilities as other more elaborated experimental models. Studies that compared empirically different quantification methods have found qualitatively identical results. Hence, for studies that do not concentrate on methodological issues itself, it seems clearly advisable to use the simplest verbal method, i.e. the semantic differential, which also was the main data raising technique of the exploratory studies of this thesis (see Chapter 7).

Nevertheless, in the long run complementary and extending data raising techniques would be highly desirable, ideally focusing on unconscious behavioral aspects. This would allow for much less obtrusive experimental designs and an increase of ecological validity, finally levelling the differences between laboratory experiments and field studies. Generally, both methodological approaches are justified, and instead of seeing them as mutually exclusive or complementary, it seems reasonable to strive for a stronger integration of advantages of both. Chapter 5 will present respective attempts based on recent advances in computer-based simulation.

Chapter 4

Describing architectural space

4.1 Introduction - from properties to numerical factors

As outlined in Chapter 2, affective qualities are an environment related and directed psychological phenomenon. In the previous chapter it has been shown that core aspects of affective experience can be qualitatively and quantitatively described by a few basic dimensions. In addition, an empirical investigation of interrelation patterns requires also a systematic description of the corresponding environments. Describing the physical environment seems at first glance much easier than capturing intangible emotions, yet actually it turns out to be a non-trivial and decisive issue: Any analytical representation needs to strive for a massive data reduction that ideally leaves only relevant information. This necessary selection and simplification of in itself objective physical properties widely influences any outcomes and potentially introduces a subjective perspective. Therefore, the exploration of physical properties that need to be considered in quantitative representations of architectural environments and the empirical testing of models on their respective capabilites have become central objectives of this dissertation project (see Chapters 7 and 8). Fortunately, this exploration could be based on already existing description systems from several disciplines that partially offered elaborated analysis models at least for partial aspects of spatial environments. Before these various approaches are reviewed, some generically preferable properties of description systems shall be described.

First of all, the scope of the models and factors should obviously fit the scale of architectural spaces and small scale spatial configurations. Methodologically, analysis methods that result in definitive sets of few quantitative characteristic values appear preferable for correlation studies. The underlying characteristics themselves shall be objectively determinable from criteria that are generically applicable to all kinds of spatial environments. Ideally, an automatic detection of the constituent properties should be possible. In analogy to the two-sidedness of affective qualities, two different perspectives for describing architectural environments can be discerned that can be characterized as environmentally centric versus perceptually / psychologically oriented. An optimal approach would consider detailed environmental information and would be at the same time psychologically or biologically plausible and backed up by empirical results. It is clear that existing description systems, theories, and models only partially fulfill this catalog of specifications, which nonetheless will be used as a guideline for the following evaluation.

4.2 Architecture

Reasoning on space has an old tradition in architecture, so, ideally, the normative knowledge of this discipline incorporates a substantial expertise based on large number of observations over long periods of time beyond the cycles and of modern science. Indeed, despite the fact that most more formalized description approaches are relatively recent developments, many parallels can be found in historic tracts and buildings that demonstrate a deliberate consideration of aspects over longer times. Finally, the diversity of approaches originating from the changing perspectives between different design and building phases make architectural description systems to a prolific source for spatial analysis.

4.2.1 Constructive description

In practical architecture, buildings and construction works are described by a combination of scale plans and contract specifications containing kind, quantities and dimensions of all structural parts. The roots of the current custom goes back at least to the middle ages (Antonow, 1993; Biller, 1998). The overall structure of this description is mainly motivated by the building process, but is remarkably similar to the way rooms or buildings are described in colloquial language ("a small room with two rectangular windows"). Likewise, a similar structure has been often used in architectural textbooks (e.g., Krier, 1989), and computer-aided design programs specific for architecture implement a similar constructive parts oriented data model. All in all, it seems to be a natural way of describing buildings. The basic elements (wall, window, column, etc.) are sometimes called architectural archetypes (cf. Section 4.2.2).

This description method evolved from the need to completely define unique cases. It fits into a recurring description scheme (see Sections 4.2.2, 4.3) that could be termed array + structure. While the description of the parts' array is quite elaborate and standardized, the structure is normally not represented numerically but graphically. For a systematic comparative approach, several difficulties arise from this use of different media for information conveyance: Direct comparability is only granted by constructive and formal identity. In this case all differences are exactly defined numerically. So, for comparing spaces that differ only in these aspects, it seems to be a very efficient description. Otherwise a form of prior categorization has to be done that can use the hierarchical structure of the description system. Here, however, potentially important detail information can be lost. Furthermore, steps of the constructive process are described that finally are not often perceivable at the surface. Since the substructure often considerably influences and the overall appearance, it might, on the other hand, be useful to consider also these properties.

4.2.2 Compositional approach

Using a similar array + structure scheme, several compilatory architectural textbooks (Ching, 1996; Krier, 1989) describe architectural form by defining a sort of language based on a few basic geometrical primitives, for example using the platonic bodies or circle, square, triangle. More complex forms are comprehended either as transformations or as compounds of the basic shapes using several identifiable common operations. Analogous to the previous approach, instead of describing the final result, steps for its genesis are defined, but from the perspective of the designer.

Also the basic geometrical elements of these systems have been called the archetypes of architecture (Thiis-Evensen, 1982). This concept was borrowed from Jungian psychoanalysis where archetypes are seen as grounded in the collective subconscious. It has led to the debate whether already some basic elements have intrinsic values, or, in terms of this dissertation, convey affective qualities (cf. e.g., Smith, 2003, pp. 197-294). Analogously, it can be assumed that transformations such as "fragmentations" or "collisions" may be affectively laden also.

For the purpose of comparing the formal differences between spatial situations, this approach has several drawbacks. Methodologically, it can be argued that a decomposition into compositional elements is often neither obvious nor unambiguous. While the number of different primitives might be manageable and their properties exactly definable, the associated operations and transformations seem much more difficult to be strictly formalized (respective attempts are summarized under the label of shape grammars, cf. e.g., Stiny & Gips, 1972). A clear description of real world examples is often difficult, and a comprehensive effort can easily become arbitrarily complex. Furthermore, a successful analysis often requires a completeness of information that is difficult to gain solely from immediate experience, but needs some sort of overview knowledge such as floor plans and cross-sections. All in all, this kind of formal analysis might mainly offer interesting insight into the underlying formal concepts from the perspective of a building's designer. The predictive value for experiential qualities seems at first glance rather limited, since the perception of the corresponding qualities requires prior aesthetic training.

Nevertheless, while the compositional approach was initially an instrument of analysis rationalizing the genesis of form, it can contribute to the understanding of the experience. Several theories suggest that it might capture important aspects of representation and highlight relations that are not obvious but possibly perceived. Since the human mind is highly trained to induce relations and structure into very complex percepts (Leyton, 2001; Graf, 2002) for tasks such as object recognition and categorization. Similar processes can be assumed to exist for the perception of architectural space.

4.2.3 Space as perceptual density field

Based on a long architectural tradition (cf. Section 2.2), Joedicke (1985) has formulated a theory of architectural space that initiates from the notion of space as "thing between", something that arises from the perception of its boundaries. Hence, the impression of space is a construction of the human perceptual (mainly visual) and cognitive system that actively forms relations between objects or locations. If space is basically a system of perceptual relations, the primary quality of this architectural space is its perceptual density, i.e. the intensity of the perceived relations.

According to Joedicke, the differentiation of space by its density is one leitmotif of architecture, particularly in former times this was deliberately used as a means of expression. Within one space, its density is not homogeneous, it seems in particular useful to differentiate between peripheral and inner density. For example, a different treatment of the peripheral density allows to distinct three basic formal categories of architectural space: (1) *Corporeal space* is formed peripheral to solid objects. (2) *Space as container* is mainly defined by its clear physical delimitation and constitutes the normal case in everyday architecture. (3) The *spatial field* is situated somewhere in between, since it is both constituted by corporeal objects and delimiting boundaries. A characteristic of spatial fields are gradients of enclosure and the continuous flow between spaces. Solid and void are the extreme cases of perceptible space. The density quality of space is mainly constituted by its shape, surface properties, and lighting. Furthermore, the temporal aspect of perception that determines the sequence of percepts and thus the formation of relations has to be considered.

While Joedicke emphasizes that spatial density is in principle exactly determinable, he sees no real use of such a quantitative approach for the practical work of an architect and abstains from further concrete statements. Other authors, however, were more interested in quantitative predications. For example, the work of Treu (1970) can be seen as an early related formal attempt, referring to the geometry of the visual space. More recently, Do & Gross (1997) and Glaser & Cavallin-Calanche (1999) have implemented software tools that calculate and visualize the rate of enclosure automatically, which can be seen as closely related to Joedicke's density. Also isovist derivatives (see next section) allow to derive similar quantitative measurands. Finally, the studies of Kim & Branzell (1995) investigate aspects of density empirically (see Section 4.3).

4.2.4 Space syntax

Space syntax is a set of techniques for the analysis of spatial configurations. Originally conceived by Bill Hillier and his colleagues at the University College London in the 1980s, it has since grown to become a tool used by an active community around the world in a variety of research areas and design applications (Hillier & Hanson, 1984; Hillier, 1996). Space syntax describes spatial configurations and forms using relatively simple relational graphs consisting of paths and nodes only, and can be seen as a formalized description system in the tradition of Lynch (1960). This operationalization allows the derivation of quantitative data about connectivity, centrality, control level etc. for complex and large-scale spatial environments.

Original space syntax analysis depended either on completely manual evaluations, or on a human-assisted semi-automatic prior partition of spaces into convex subunits as first step towards an abstract representation. However, this initial operation is intricate, often ambiguous, and therefore somewhat arbitrary. Due to that, several alternatives have been developed.

In response to the reported shortcomings, there have been attempts to base space syntax on *isovists* (Peponis, Wineman, Rashid, Kim, & Bafna, 1997; Turner, 2001). Benedikt (1979) has proposed isovists as objectively determinable basic elements

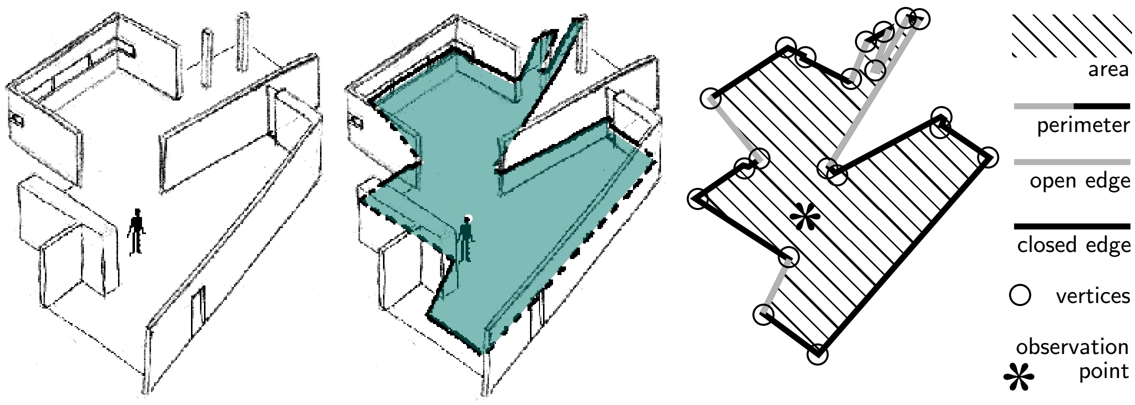


Figure 4.1: Generating isovists: Left: a hypothetical indoor environment; middle: the gray area is visible from the person's observation point within the environment; right: the resulting isovist and its basic measurands.

for analyzing spatial characteristics of architectural environments. Isovists are viewshed polygons that capture spatial properties by describing the visible area from a single observation point (see Figure 4.1). From the isovist polygons several quantitative descriptors can be derived that reflect physical properties of the corresponding space such as area, perimeter length, number of vertices, length of open or closed edges, etc. These basic measurands are directly comparable and can be combined to generate further integrative characteristic values such as roundness and vertex density (for an applied example see Section 7.4).

Isovists basically describe local physical properties of spaces with respect to single observation points. In order to better describe the spatial characteristics of an environment as a whole, Turner, Doxa, O'Sullivan, & Penn (2001) have proposed the technique of *visibility graph analysis* that integratively considers multiple positions within an environment. This technique approximates isovist polygons by an intervisibility graph based on discrete voxel-like spatial elements (See Figure 4.2). As shown in Figure 4.3, typical visibility graph measurands are neighborhood size (i. e. isovist area) and clustering coefficient (i. e. relative intervisibility or visual stability within an isovist, information that may be relevant for locomotion and navigation). Additionally, Psarra & Grajewski (2001) have proposed a related analysis technique that concentrates on the visibility graph or space boundaries. They assume them to be the visually most important region of a viewshed.

The original space syntax representations (mainly connectivity graphs) have been developed to analyze spatial configurations from the room layout of building complexes to city quarters. Hence, properties at a smaller scale level are not well represented. However, this scale segment seems to be well covered by visibility

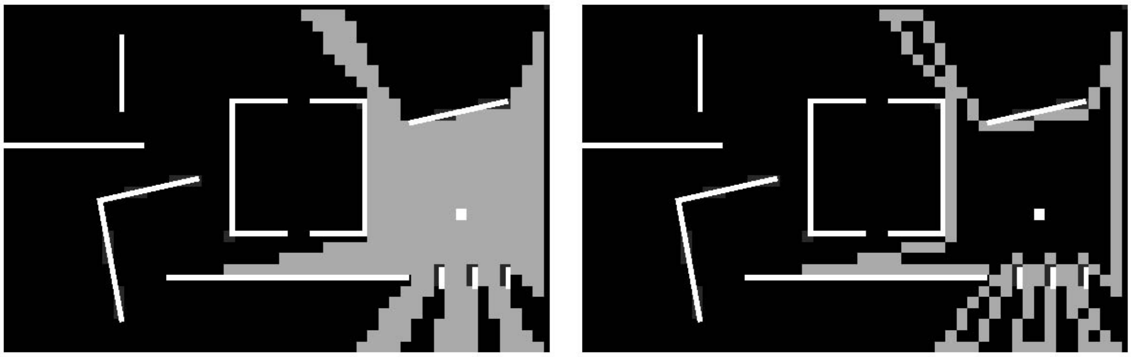


Figure 4.2: Graphical representations of a single isovist's area and perimeter, the basic elements of a visibility graph. These measurands correspond to the visible area and boundaries from one standing point.

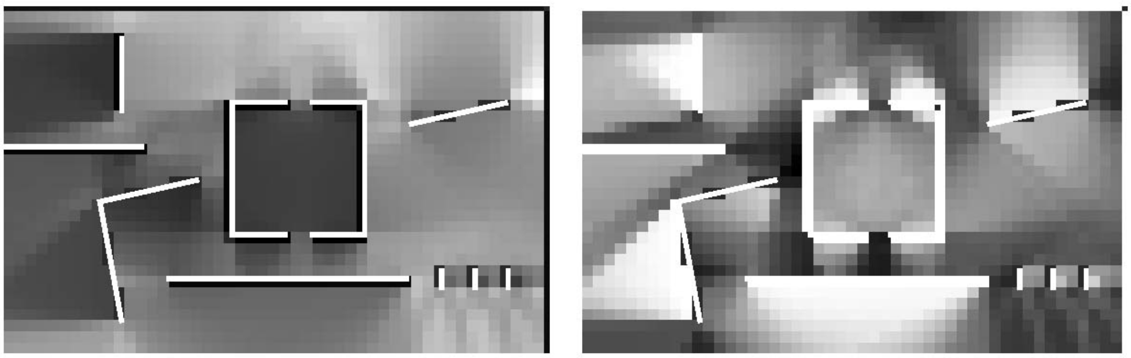


Figure 4.3: Neighborhood size and clustering coefficient measurands for a hypothetical gallery space. Lighter shading tones mean higher values.

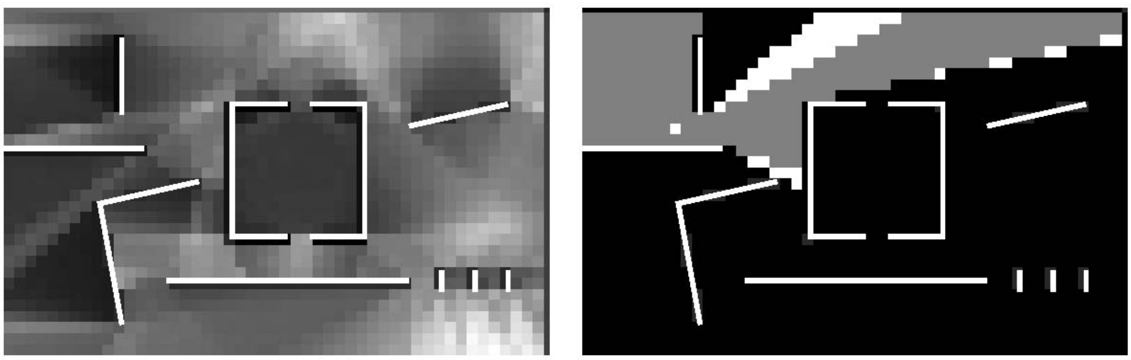


Figure 4.4: Graphical representations of isovist roundness values (i. e. squared perimeter / area), and of the information gain by one (analytical) step.

graph analysis, since its resolution can be easily adapted for describing formal properties of single rooms at an arbitrary precision.

Originally derived from abstract spatial analysis, the relevance of isovists and visibility graphs was not backed initially by psychophysical empirical findings. However, isovists describe spatial properties from an inside beholder-centered perspective, and there is first empirical evidence that they capture environmental properties relevant for spatial behavior and experience. For example, case studies on spatial behavior in the Tate Gallery (Hillier, Major, Desyllas, Karimi, Campos, & Stonor, 1996; Turner & Penn, 1999) have revealed high correlations between visibility graph measurands and the statistical dispersal of visitors. Readinger (2002) has found indications for the relevance of isovists for the perception of object configurations. Wiener & Franz (2005) and Wiener et al. (2005) have found that basic isovist properties can be perceived well and that derived measurands are effective predictor variables for human behavior and performance in certain navigation tasks. Finally, it is worthwhile mentioning that, although originating from an abstract analytical background, space syntax is in certain aspects similar to current biologically and empirically motivated models of spatial memory (see Section 4.4.3).

4.3 Gestalt psychology

Classic gestalt psychology (e.g., Köhler, 1947) investigates the phenomenon of induced perceptual relations between percepts that can be qualitatively described by few distinct gestalt rules. The concept of fields of perceptual forces around objects was introduced to describe the interaction of several gestalt principles (Arnheim, 1977). Initially, Kim & Branzell (1995) empirically tested the concept for spatial stimuli by psychophysically quantifying the limits of perceived relations between free standing columns. Their results showed that these perceptual forces are a normal quantifiable psychical phenomenon.

Gestalt psychology has become very popular and influential on art theory and analysis. For example, the mentioned compositional description systems are obviously influenced by it (see Section 4.2.2). In the array + structure description scheme, Gestalt laws can be seen as an attempt to identify single perceptual structuring operations. Yet, hard formalized systems and quantitative predications are a recent development influenced by information theory (Geissler, 2001). The traditional method related to art description (e.g., Oostendorp & Berlyne, 1988) is mainly phenomenally oriented, therefore a strictly formal implementation has not been attempted.

4.4 Perceptual and cognitive psychology

4.4.1 Scene and object recognition

The image based model of visual recognition sees objects mainly represented by combinations of canonic snapshots consisting of characteristic global and local pictorial frequency spectra (Poggio & Edelman, 1990; Bülthoff & Edelman, 1992). The model is backed by strong physiological and psychophysical findings and is well suitable for implementations in machine vision and computational scene and object recognition. A Fourier transformation or Gabor Filtering allows a relatively simple detection of features in a similar way to the early visual brain areas (Olzak & Thomas, 1986). Trained on test samples, a classification algorithm based on frequency distributions can be very efficient when sorting scenes in basic dimensions or into basic categories (Oliva & Torralba, 2001; Torralba & Sinha, 2001) similar to humans (Fenton, 1988). In addition, further visual characteristics (e.g., color, lighting, roughness) find direct correspondences in the digital image representations and can easily be easily analyzed (see Section 7.2).

Alternatively, the part based theory of object recognition (Biederman, 1987, 1995) describes objects by invariant relations of a set of geometrical primitives (geons). While this representation seems to correspond intuitively well to introspection and has the advantage of being relatively independent of view direction changes, it requires a prior segmentation and identification of parts, which is a non-trivial problem for computer vision implementations. A further drawback is the insufficient psychophysical evidence (Wallis & Bülthoff, 1999).

4.4.2 The ecological view of perception

Gibson's ecological approach to perception (1979) focuses on the one hand on invariants in the environment (i.e. perceptual properties that stay constant under active ego-motion), and on the other hand on active information pick-up as evident in the concept of affordances (i. e. action-relevant information for an organism about the properties of its environment, cf. Guski, 1996, p. 46). The latter implicates a demand for a higher level description, seeing environments basically as an array of functional units, similar to the way spaces are composed in early stages of the architectural design process when coarsely arranging structural and mainly functional components.

While Gibson gives several examples for affordances, he does not provide an elaborate description system. Probably he would have conceived a situation-independent environmental analysis as inappropriate for the dynamic process of spatial interaction, which lends itself best to direct observation and post-hoc explanation. Hence, the ecological view is mainly an important perspective on potentially important factors depending on the situation and context. This perspective has been influential on environmental psychology via the concept of behavioral settings (Barker, 1968, see also Section 6.4.1).

4.4.3 Theories of spatial memory

Another direction to approach to the description of environments arises from the study of animal and human navigation and wayfinding behavior. It is generally taken for granted that goal-directed specific spatial behavior beyond the sensory horizon such as route planning needs some form of internal representation. Consequently, there have been numerous attempts to identify basic elements organisms use to abstract and breakdown their environment (for an overview see, e.g., Tversky, 1993; Montello, 2003; Wiener, 2004, pp. 6-13). For a further classification of proposed constituents, a distinction between format, structure, and content has turned out to be useful.

An early framework for the mental representation format of space was Tolman's (1948) concept of cognitive maps implicating a quasi-metric representation of places. The concept of places here is relatively broad and open, and can denote anything distinctive in an organism's environment. Recent authors (e.g., Schölkopf & Mallot, 1995) rather prefer graph representations that are much more flexible than metric maps and at the same time economic and mathematically well defined. Furthermore, they can account for many empirically observable effects and in the human selection of routes (Gillner & Mallot, 1998; Steck & Mallot, 2000) that are inconsistent with a homogeneous map. Concerning the structure of spatial memory, recent studies (Wiener & Mallot, 2003) strongly suggest the existence of hierarchical levels complementing non-hierarchical structures (Kosslyn, Ball, & Reiser, 1978).

With respect to the content, Kevin Lynch (1960) postulated in his famous seminal book that the mental representation of cities is made-up of a network of the basic elements paths, edges, districts, nodes, and landmarks. Later empirical studies substantially backed his framework that initially was mainly phenomenologically based. Alternatively, based on considerations on the economic encoding of spatial information, studies on insects, and parallel models of object recognition (Poggio & Edelman, 1990; Wallis & Bülthoff, 1999, see previous section), Schölkopf & Mallot (1995) have proposed sets of pictorial environmental snapshots as a plausible minimal form of content representation. Further studies (Gillner, 1997; Steck & Mallot, 2000; Wiener & Mallot, 2002) indicated that this basic principle is also transferable to humans, yet humans seem not to depend on pictorial identity but can alternatively use abstract structural and geometrical information (Restat, 2003).

All in all, in principle the outlined research direction offers a very promising and biologically backed fundament for spatial analysis. However, despite lots of convincing single findings, the current state of knowledge is also here far from comprehensive, a theory of spatial memory of general consensus is still not yet available. Hence, the definitive form of spatial analysis cannot be derived from theories on spatial memory yet. Nevertheless, depending on the requirements, theories of spatial memory are capable of offering useful and well-developed components, in particular for large-scale environments. Their selection and implementation into a concrete analytical system is nevertheless in the responsibility of the practitioner.

4.4.4 The geometric module

An additional conceptual "geometric module" has been proposed as typical representional content of human spatial memory especially for small-scale spatial situations (Wang, 1999; Wang & Spelke, 2002; Werner & Long, 2003). Recent research could show that both the layout and the geometric shape of an environment are of primary importance for an organism's self-location and the encoding of object positions in spatial memory. Interestingly, geometry information appeared to rule out other cues such as color in animals and infants (Gouteux & Spelke, 2001), while for adults both kinds of information were equally accessible. These results have been interpreted as evidence for a different kind of content representation. While the studies only tested the efficiency of a few geometric configurations and therefore do not allow detailed and systematic predications, they at least offer an additional biological motivation for geometric analyses as described in Section 4.2.2 and 4.2.4.

4.5 Summing up

Architecture and environments in general can be described using several existing distinctly different methods. None of the currently existing description systems can claim to be truly comprehensive, but, since these approaches are by no means mutually exclusive, they offer considerable alternatives one can choose among depending on the particular purpose.

From a practical analytical point of view, visibility graph analysis and the computational vision approach appear particularly promising, since they both offer well-developed and generically applicable methods. While the two description systems concentrate on quite different aspects of environments, both are clearly perceptually oriented. Therefore, in addition a more representational or object-oriented approach seems to be a further worthwhile alternative to be considered in empirical applications. Together this ensures that a diverse spectrum of properties is covered.

A further preselection with regard to suitability for the initially defined purpose does not seem possible. Hence, in Chapter 7 all three methods are empirically explored. Their specific advantages and disadvantages are subsequently compared and discussed in Section 8.3.

Chapter 5

Using VR for architectural simulation

Subsequent to the review of methods to quantify and describe emotions and architectural properties (Chapters 3 & 4), this chapter will now discuss practical and methodological issues of empirical investigations on affective qualities of architectural space. Section 5.1 transfers the general discussion of Section 3.5 to the particular context of architectural research and simulation. Classical simulation and representation media are reviewed in Section 5.2. In Section 5.3, virtual reality as medium for architectural simulation is introduced and its particular advantages and drawbacks are discussed. Then, Section 5.4 presents a small case study exemplarily comparing the perception of architecture in VR and reality. Finally, in Section 5.5 specific technical design issues of architectural VR simulations are discussed in more detail. While the last section may appear at first glance slightly peripheral for the overall scope of the dissertation, the topic is actually closely connected to the central objective of identifying physical correspondents to experiential qualities: If the primary factors affecting architectural experience and spatial behavior were known, simulations could particularly concentrate on rendering those aspects realistically. And vice versa, studies on parameters affecting simulation validity provide useful hints about physical factors that obviously influence the experience of architectural space.

5.1 Introduction - why simulation?

Architectural simulation may be of interest for various reasons. From the perspective of architectural practice there are obvious economic reasons to consider the simulation of planned building projects beforehand: Simulations offer the potential to base the design process on immediate inspection, different alternatives can be evaluated without the need of expensive reconstructions, and simulations may allow direct changes in a highly responsive manner. Likewise, typical procedures of the architectural decision process demand for representation media. For example, in architectural competitions numerous proposals have to be reviewed synoptically. So, even if it would possible to find a good correspondent to a planned room in real world, it might be still preferable to examine it in a same constant context and format as potential alternatives.

As regards scientific research in the domain of architectural perception and spatial behavior, the principal considerations laboratory experiment versus field study as presented in Section 3.5 can be directly transferred on considerations on simulations: In these disciplines, laboratory methods can only applied using simulation media. For highly exploratory research such as this dissertation, in particular the flexibility of simulations may be a decisive argument. In case that the exact quantitative relations are to be determined, the level of control may be of primary importance.

5.2 A glance at classical simulation media

Since the renaissance at least, various media have been used to convey preliminary perceptual impressions of a proposed or planned architecture. The classic means of expression of architectural ideas are *perspective drawings* and *scale models*. Both can be very efficient media containing and conveying a lot of information. Yet it has to be considered that particularly drawings are not a simulation medium, but a way of developing, communicating, and presenting ideas. So it is natural, at least for professionals, that these representations can stay rather abstract and usually have to be interpreted or commented. The outstanding advantage of the scale model is the possibility to behold it easily from different observation points and to interact with it intuitively. Yet this feature is at the same time one of its inherent dangers, since the perspectives from which the model is examined often do not correspond to the real views. For example, normal small-scale models are mainly seen from aerial perspectives which are irrelevant for and not accessible by later real world experience. Also the real dimensions and scale can be severely misjudged.

In response to these drawbacks and inaccuracies, the method of *architectural endoscopy* has been developed. This technique uses miniaturized cameras to get impressions from scale models that correspond well to the later perspectives of real-world beholders (Markelin & Fahle, 1979). Architectural endoscopy also allows an accurate physical simulation of lighting conditions. The main disadvantage of this medium is its high level of expenditures. First very accurate scale models have to be built, and then an elaborated and expensive technical equipment is required. Another approach to avoid the drawbacks scale models is the use of *full scale mock-ups*. Despite the obvious expenses, several variants have been propagated. For example, Alexander (1977) recommends to make use of very provisional installations directly on the building site even during the early design stages. Similarly several architectural universities (e.g., TU Vienna Martens, 1999; Martens & Voigt, 2001) have established space laboratories that provide installations and elements to facilitate full scale indoor mockups. And finally, in some rare cases (predominantly for the exterior of representational architecture in the first decades of the last century) completely accurate visual clones have been built. This method is nowadays mainly used for small snippets of larger facades, to make final functional, color, or small design adjustments.

The technical advances of the last century have also led to further developments that are to some degree in the tradition of classic architectural drawings. First of all, just for presenting already existing architecture under constant laboratory conditions or at distant places, *photographs* and *slide projections* have been used, particularly for environmental psychology studies in the 1970s. Likewise, *video presentations* offer a means to store and present dynamic and even multimodal impressions. For non-existing architecture, classically *photomontage* has been used, and the development of non-interactive computer graphics gradually allowed to synthesize similar representations from virtual full scale models, starting from simple perspective drawings over shaded still *renderings* to finally quasi-photorealistic and physics-based cinematic *animations*. The related area of interactive computer graphics (virtual reality) is reviewed in the following section.

Regarding the validity of conventional simulation in general, several studies of environmental psychology have investigated the effects of various presentation methods and stimulus qualities. In most experiments pictorial quality turned out to be a key requirement for resembling reality, whereas the size of the medium, animation, or ego-motion turned out to be secondary (Stamps, 2000; Daniel & Meitner, 2001). All in all, the studies suggest that evaluations under different media and in comparison to reality are surprisingly stable. It seems that simulation media rather gradually affect the intensity of responses to environmental features, but normally do not change the general directions (Hershberger & Cass, 1988).

5.3 VR simulations: General characteristics

Virtual reality (VR) was one of the more glittering aspects of the IT revolution of the 1990s that, due to movies such as "Total Recall", "The Lawnmover Man", or "The Matrix", has also gained considerable public attention. In the same time, VR raised expectations both in the domain of architecture and experimental psychology. These early years were followed by a phase of somewhat disillusion soon after the millennium. The hope of early breakthroughs could not completely be fulfilled. However, this disappointment was maybe rather caused by unrealistic expectations than by failures of the medium itself, because VR offers not revolutionary, but substantial solid qualities. For the area of perceptual psychology, Gillner (1997) and Bülthoff & van Veen (2001) have thoroughly discussed the general characteristics of VR, thus only the most important points shall be recapitulated briefly.

Most condensed, VR may be defined as a computer-generated multi-modal interactive environmental simulation that conveys a sense of presence. This brief sentence contains already all of its constituents. Of course, many real existing simulations that are considered as virtual reality only consist of a reduced subset of these features, nevertheless, one can at least say that computer simulation, multimodality, interactivity, and presence are at least typical characteristics. Since VR simulations widely differ with regard to their technical implementation, there arose the need of somehow comparing them. For describing at least qualitatively the degree of perceptual realism and (multi-modal) completeness, the concept of *immersion* has been introduced. However, because a high degree of immersion does not guarantee the success of a simulation for a particular purpose, several further concepts have been developed to characterize and evaluate VR simulations. Some authors (e.g., Regenbrecht, 1999; Riecke, 2003, pp. 122-140) concentrate on the term of *presence* (i.e. the subjective sense of being there) as a to some degree transferable general criterion, while others rather prefer more task-specific or object-related criteria such as credibility, believability (Cunningham, Breidt, Kleiner, Wallraven, & Bülthoff, 2003), or just informational correspondence *(Stappers, Gaver, & Overbeeke, 2003).* As regards the scope of this dissertation one could establish *affective equivalence* as integrative quality and comparison criterion.

Comparison VR to other simulation media. Figure 5.1 displays a three dimensional conceptual dimension space useful for the general comparison of simulations. Most basically, one could say that generally promising simulations offer a wide sensory completeness and a substantial potential of interaction at a high level of detail or environmental richness. All three quality criteria contribute to the general potential for providing realism. At the same time, all three criteria

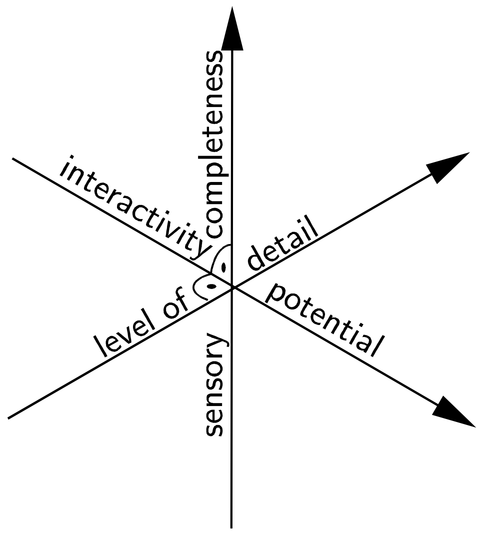


Figure 5.1: Conceptual principal dimension space of the realism of spatial simulations.

normally increase the necessary technical or preparatory effort. If one compares VR to classical simulation media as presented in Section 5.2, it becomes apparent that VR has a particular potential with respect to interactivity, but also as regards sensory completeness or multi-modality. This outstanding potential of interaction makes VR very promising for empirical experiments, since experimental tasks can be seamlessly integrated into the stimulus presentation, and real behavioral data can be recorded in a non-oppressive indirect way. Finally, restrictions that exist in reality or when using physical mockups can be overcome, the physical laws and settings can be freely adjusted as required for a particular experimental question.

Yet of course all media have their weak points. For their discussion it seems useful to differentiate between obvious drawbacks and hidden ones. While the former are mainly annoying, for example the often mentioned conflict in VR between photo-realistic textures and their repetitive application, the latter are more dangerous, since they convey wrong information which is important to be aware of. Classic simulation media convey the impression that obvious conflicts are mainly a matter of customization of the beholders, or from the designer's standpoint, a matter of a well-considered level of abstraction. Here a novel medium may have disadvantages, since people are not yet accustomed to its appearance, and do not yet know how to interpret it correctly. It can be assumed that such effects may especially occur if a medium comes very close to reality, which may tempt to confuse representation and reality. Hence, potential influences and side-effects of VR shall be carefully analyzed in the next sections.

5.4 The question of validity

Introduction. As outlined in the previous section, virtual reality offers promising qualities both for architectural simulation and perceptual experiments. Yet, since VR is a novel medium, the question has to be raised as to what degree experiences in VR can be transferred to reality. Validity criteria can be defined more generically for architectural simulation in general or more narrowly for the particular main goal of investigating affective responses to architectural properties. Unfortunately, the current state of knowledge represented in literature does not allow conclusive statements on the general validity of VR for architectural simulation. Although there are several studies comparing aspects related to architectural perception between VR and reality, the transferability of their findings cannot be taken for granted a priori. VR simulations consist of many design aspects that all contribute to a vast parameter space. Due to possible interactions and unknown mutual influences, all general predications based on current studies have to be seen as provisional. Therefore, this section mainly reports a case study that exemplarily tested the validity of a particular VR simulation that was seen as representative for the following main studies (Chapter 7).

Literature review. Most basically, it can be said that VR simulations principally have the potential for investigating behavioral responses to spatial environments. Jakob (2004) has shown that architectural elements such as the wall are conceived in virtual reality similar to the real world, and influence behavior in a similar manner. Besides the apparent willingness of people to accept VR structures as valid representations of reality, further studies document that simulated spatial stimuli are also capable of eliciting involuntary affective reactions analogous to real spaces. Studies on acrophobia (Regenbrecht, 1999) and tunnel phobia (Mühlberger, 2001; Chatziastros & Mühlberger, 2003) have convincingly demonstrated that already current VR simulations can induce real emotional episodes in susceptible persons despite their obvious artificiality. Nevertheless, a direct experiential correspondence cannot be taken for granted, it is probable that any particular setup has tendencies to affect responses.

Henry (1992) was probably the first who examined spatial perception in VR in an architectural context. In his seminal study he postulated three principal requirements for a generally valid architectural simulation: VR has to provide information similar to reality about dimensions, atmosphere, and configuration. In his empirical experiments in a vacant exhibition hall he compared several setups with a reality condition. The experiment yielded promising results for the feel of spaces and configurational knowledge, but showed significant compressions of perceived spatial dimensions in all VR conditions. A further similarly comprehensive case study by de Kort, Ijsselsteijn, Kooijman, & Schuurmans (2003) compared standard environmental psychology experimental methods in a real building to a corresponding VR representation. Their results widely approved Henry's findings apart from the finding that in their study the exclusively vertical dimension estimates were much closer to reality.

Further studies on affective responses to architecture in VR are not known to the author. Yet several further studies tested the acquisition or replication of configurational knowledge in VR, and consistently reported good performances (Psotka, 1995; Koh, von Wiegand, Lee Garnett, Durlach, & Shinn-Cunningham, 1999; Sellen, 1999; Riecke, von der Heyde, & Bülthoff, 2001). And an even larger number of studies compared dimension and distance estimates in real and virtual scenes. The general picture here is not clear. Most of them reported strong underestimations in VR, for example Willemsen & Gooch (2002), Surdick, Davis, King, & Hodges (1997), and Witmer & Kline (1998) in contrast to Waller (1999) who found very accurate results in VR. Beyond mere comparisons, several studies investigated the effects of changing single simulation properties. For example, Willemsen & Gooch (2002) studied the influence of model quality on dimension estimates in VR, compared to reality. They did not find a significant difference between their two different VR qualities (photographic panorama roundshot, simple shaded standard model), concluding that observed systematic underestimates must have been caused by other factors.

Objective. As a starting point for further VR experiments of this dissertation project, a pilot study was conducted in order to exemplarily compare spatial perception and experience in real and corresponding virtual rooms. Methodologically, it resembled to some degree the study of Henry (1992), but other categories of rooms were chosen. Furthermore, a completely different kind of setup and simulation was used, hence, a direct transferability of his findings could not be taken for granted. The experiment was intended as an anchor point for subsequent studies. It was hypothesized that perception and experience of the selected architectural spaces would not significantly differ between VR and reality. In case that this hypothesis could be basically approved, further experiments could use this study as a reference for their assumed transferability; if not, the study might reveal critical factors requiring further research and provide insights for improving future simulations.

Method. The experiment consisted of a comparison of affective appraisals and distance estimates in real and corresponding virtual spaces (Figure 5.2). Despite their well-known drawbacks (e.g., high level of variance, preferences for simple numbers), numerical metric dimension estimates were chosen for two reasons: They were completely portable between the experimental conditions and un-

(a) (b)

Figure 5.2: Example scene from the preparatory study that compared the experience and the perceived dimensions in three virtual rooms (a) and their real correspondents (b).

likely to induce cheating. The experiment used a between-subject design and consisted of two different experimental conditions: In condition 1, three real rooms of an institute building were shown to one group of 20 participants (10 female, 10 male). The subjects could explore the rooms freely for 30 seconds, afterwards they were asked to rate the experiential qualities along nine principal categories of architectural experience (interestingness, comfort, beauty, calm, simplicity, spaciousness, enclosure, brightness, and clarity) using the semantic differential scaling technique. As second experimental task they then estimated two principal room dimensions and one egocentric distance from a fixed observation point in each room. The sequence of experiential ratings was randomized, but the principal order of scenes and rooms was fixed over both conditions and all participants. The second group also comprised 20 (10 f, 10 m) participants, yet, instead of the real rooms, three corresponding high-quality computer-generated spherical roundshots were presented. During the experiment they were seated in front of a flat projection screen whose physical visual field spanned about 86x63 degrees (simulated FOV 78°x57°) at a distance of 102 cm. The real eyeheight was about 110 cm over the floor, while the virtual eyepoint was fixed during the experiment at a height of 160 cm; the gaze direction could be adjusted using cursor keys on a standard keyboard.

Results. Regarding the affective appraisals (Figure 5.4), the results of the VR condition were generally very similar to the ratings of the corresponding real rooms. The only category showing significant and consistent differences over all scenes was arousal (arousing - sedative). VR scenes were consistently rated to be more arousing. The results of the size and distance estimate experimental task

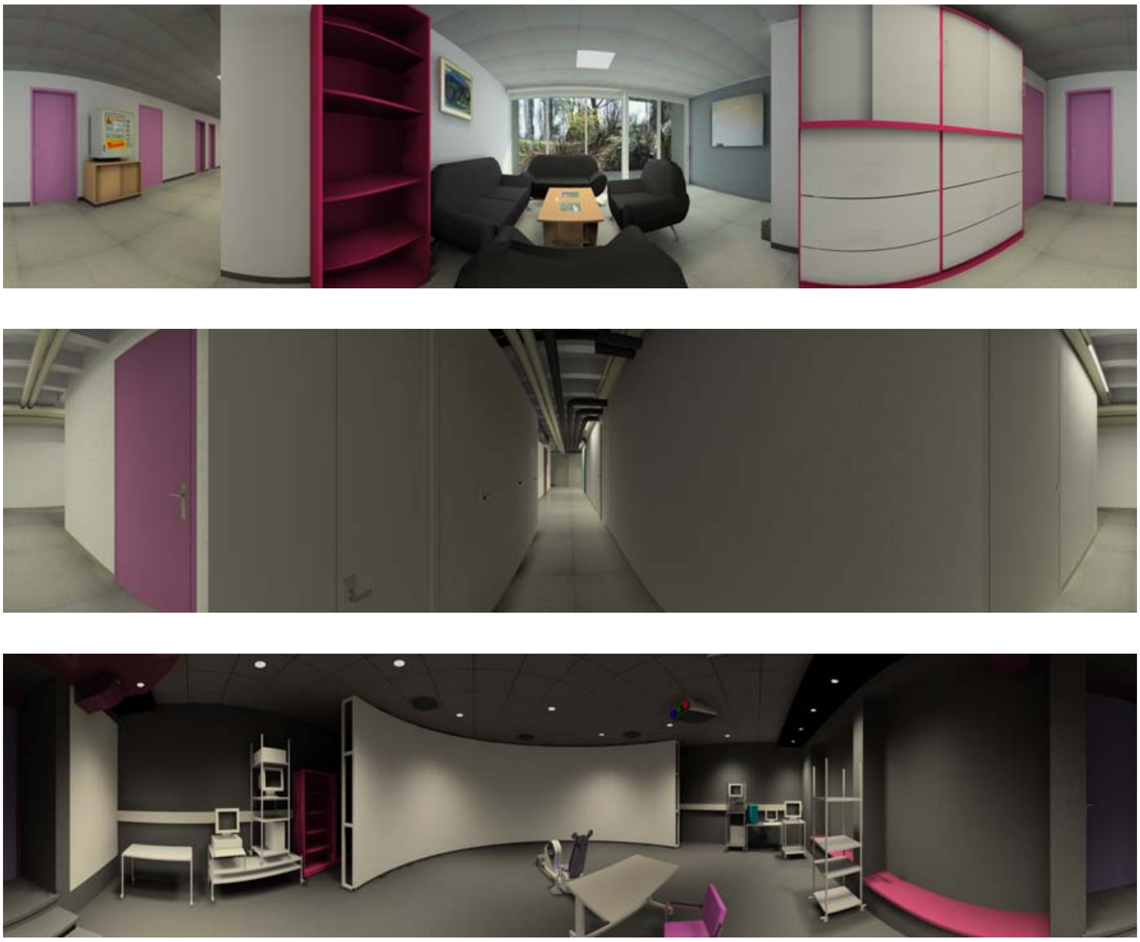


Figure 5.3: The three scenes of the VR versus reality comparison experiment, unwind of the cylindrical renderings used as stimuli in the VR condition.

conveyed a different impression (Figure 5.5): In all three scenes both allocentric and particularly egocentric distance estimates differed significantly between VR and reality, sizes and particularly egocentric distances were perceived substantially smaller in VR.

Discussion. Although there were some differences in the rated experiential qualities, most notably along the important arousal dimension (which could be tentatively explained by the unfamiliar experimental setup), the general outcomes of this experimental task support the hypothesized validity and transferability of the chosen simulation as regards affective qualities. Therefore, the actual poor performance of the VR condition in conveying absolute dimension information was rather surprising. Since spatial vision is based on an integration process of several depth cues (for an overview see, e.g., Cutting & Vishton, 1995; Cutting, 1997), and VR normally simulates only a part of them, this outcome may be tentatively ascribed to cue conflicts. For example, the pictorial cues conveying a 3D scene conflicted with the fixed physical screen distance, resulting in fixed disparity and accommodation information. Also, the constant virtual observation point conveyed no motion parallax, whereas in reality subjects could walk around freely. In addition, there were conflicts between the simulated and the physical field of vision, and between the virtual and real eyepoint height. The chosen setup implicated a somewhat unnatural placement of the viewer. Subjects sat on a low chair, and the viewing direction was slightly upwards. The scenes were rendered for an eye height of 1.60 m. Since eyeheight scaling has been identified as an important source particularly of depth information in monocular viewing situations (Loomis, 1999; Dixon, Wraga, Proffitt, & Williams, 2000; Ooi, Wu, & He, 2001), a scaling down effect would be expected.

It is very likely that the observed distortions were caused by a combination of more than one of these factors. Apart from the technically determined fixed screen distance, most of them are easily adjustable. Thus the tweaking of parameters may offer a considerable potential to overcome the problem by careful psychophysical calibrations. Although many VR factors might be involved, the problem itself does not seem to be specific for virtual reality, but related to the general perceptual problem of reconstructing three-dimensional space from 2D percepts, comparable to the interpretation of pictorial space (cf. Hecht, van Doorn, & Koenderink, 1999; Koenderink, van Doorn, & J., 2000; Koenderink, 2001).

Conclusion. All in all, while in both tasks significant differences between the reality and VR condition were found, the relative differences between the scenes were widely preserved between the experimental conditions. Therefore, studies that investigate effects of relative differences within one medium should not

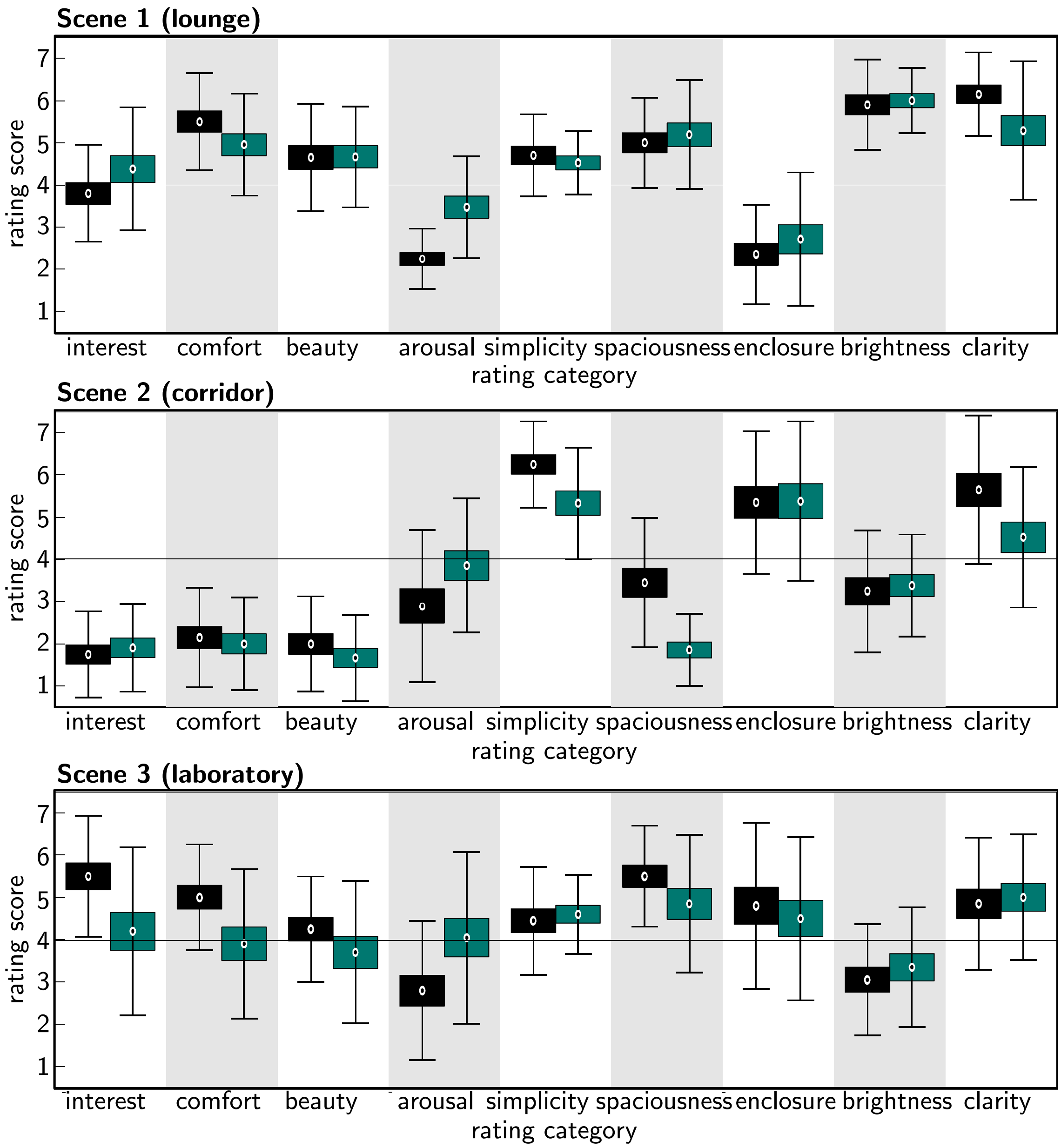


Figure 5.4: Semantic differential rating results comparing reality (black, left) and VR (green, right) conditions.

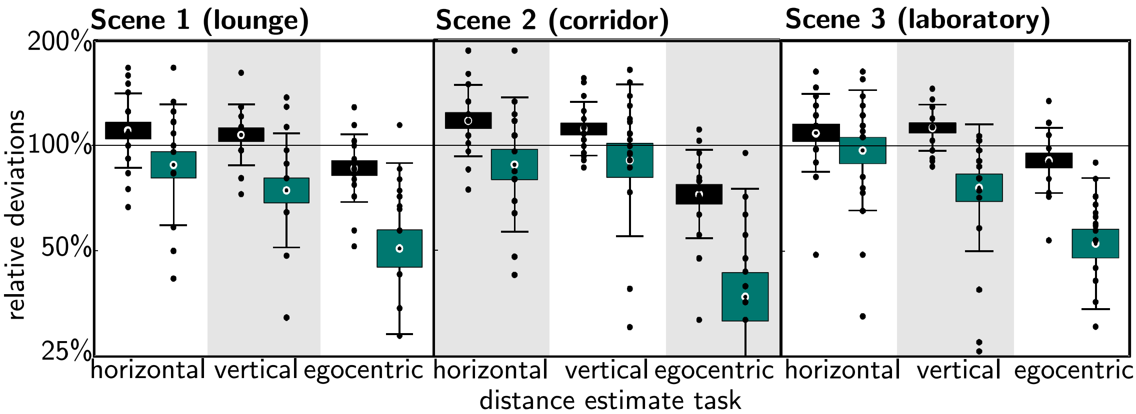


Figure 5.5: Distance and dimension estimate results results comparing reality (black, left) and VR (green, right) conditions.

be negatively affected by biases caused by the simulation, relative predications appear directly transferable.

5.5 Influences of simulation parameters

The study presented in the previous section widely affirmed the general picture conveyed from the literature that, despite a good correspondence concerning experiential qualities, VR simulations tend to affect dimension and distance estimates systematically. The general design of simulations makes it very likely that several parameters actually influence spatial perception in VR. From an engineer's practical point of view, factors that inhere certain ranges for adjustments are particularly interesting, because they may offer a potential to improve a simulation's quality. Hence, in the following particularly the influences of software-dependent parameters shall be analyzed.

Background spatial vision. For understanding the problem of distance distortions in virtual reality, it seems worthwhile to briefly review human spatial vision in general. Visual spatial perception is the prime example of perception as active integration and construction process. Depending on the criteria, about nine independent kinds of visual properties that convey spatial depth information can be discerned[1]. In the depth range that is of primary interest for the perception of architectural spaces (approx. 2-15 m), distance estimates may be based on occlusion, height in the visual field (Sedgwick, 1973; Loomis, 2001; Ooi et al., 2001), relative size including perspective, motion disparity, binocular disparity, relative texture density (Gibson, 1950, 1979), and vergence (Collewijn & Erkelens, 1990),

[1]For a compact general digest see Cutting & Vishton (1995) or Cutting (1997).

roughly sorted in order of effectiveness as outlined in Cutting (1997). From these cues, disparity, height in the visual field, and motion perspective inherently convey absolute information. The effectiveness of the cues relative size and texture density depends on the availability of absolute anchor points (e.g., familiar size of scale objects, cf. Fukusima & da Silva, 1999), while the others probably mainly offer ordinal information. The human visual system appears to be very flexible in using different cues for reducing the inherent under-determination. However, it is not yet completely clear how these informations are integrated. Recent models of spatial vision suggest that the integration of different depth cues by the human visual system can be formulated in many cases using Bayesian decision theory (e.g., Bülthoff & Mallot, 1988; Landy, Maloney, Johnston, & Young, 1995; Bülthoff & Yuille, 1996; Ernst & Bülthoff, 2004), basically meaning that cues are weighted by their reliability and consistency.

Spatial vision in VR. Due to technical limitations, all VR setups simulate only a subset of depth cues. On conventional displays and projection screens, only pictorial cues such as occlusion, relative size, and texture density are available. Stereo systems such as some head-mounted displays may additionally offer disparity and vergence information. Yet normally, vision in VR shares many characteristics with the visual perception and interpretation of 2D images. There is a substantial body of literature about the special conditions, distortions and ambiguities introduced by the pictorial representation of space (e.g., Hecht et al., 1999; Todd, Oomes, Koenderink, & Kappers, 1999; Koenderink et al., 2000; Koenderink & van Doorn, 2003). Partially, these underdeterminations can be cleared in VR due to dynamic presentation (resulting in motion parallax).

The simulated depth cues are accompanied by further consistent yet adversary cues mainly originating from a fixed physical screen distance (which may, if perceivable, be an important basis for the interpretation of scenes, cf. Goldstein, 1987) and a restricted physical field of view. Current theories of cue integration (see previous paragraph) suggest that normally all available cues are mandatorily integrated weighted by their reliability and consistency, a process which is only partially cognitively penetrable (Ernst & Bülthoff, 2004). This implicates that consistent cues such as accommodation to screen distance, even when obviously counterproductive, do considerably influence the overall perception. In particular the often observable compressions of egocentric distances may be well explained by this theory.

However, the model of cue integration might also lead to applicable workaround solutions: Shortcomings caused by adversary depth cues might be overcome by slight opposite exaggerations of easily adjustable simulation parameters which then together convey a correct overall impression. The following sections will therefore briefly present studies that investigated effects of single simulation parameters. If substantial on distance perception were found, they might be used as generic calibration parameters.

5.5.1 Eyepoint height

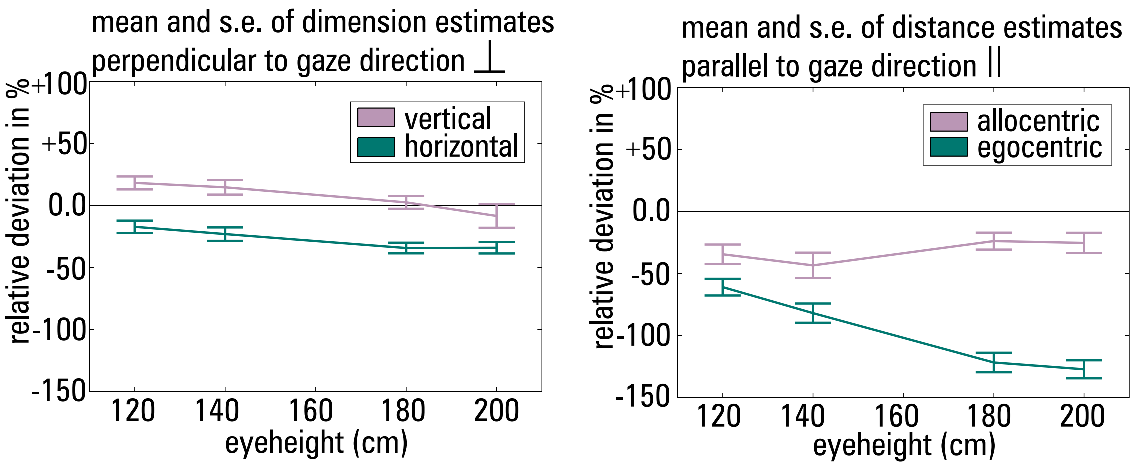
Introduction. Virtual eyepoint height is an easily accessible camera parameter that can be adjusted in any simulation setup. However, up to now, only few studies have concentrated on effects of this parameter. For example, Baumberger, Flückiger, & Favre (2001) have tested its influence on the accuracy of placing objects in VR and found a positive effect when the eyeheight was increased. Dixon et al. (2000) and Wraga & Proffitt (2000) compared size estimates at different simulated eyeheight levels in several virtual reality simulators. They only found significant effects for head-mounted displays.

Objective. In a small study, the influence of the virtual eyepoint height on size and distance estimates in VR was tested empirically. Additionally, the suitability of virtual eyeheight as tweaking parameter for architectural simulations was coarsely evaluated by testing for influences on the experiential qualities of the virtual scenes. For a more detailed description please refer to Franz et al. (2003b).

Method. In the perceptual experiment, nine subjects in two groups estimated the three principal space dimensions (perpendicular to gaze direction), two egocentric distances (the distances between the virtual observation point and two adjacent walls) and two allocentric distances (between a marker on the floor and a wall) parallel to gaze direction in two different sets of 20 virtual rooms. In addition, the experiential qualities of subsets of four scenes were rated in seven principal categories using the semantic differential scaling technique. The scenes were made with a script-based parametric modeling tool (cf. Section 5.6), for a detailed description of them please refer to Section 7.3. Each room was shown at a randomized virtual eyeheight of either 1.20m, 1.40m, 1.80m or 2.00m. The real eyeheight was fixed at 1.38m with a chin rest. The stimuli were presented on a 130x90 degree wide-angle spherical projection system (Figure 5.6) at a resolution of 1024x768 pixels.

For the experimental analysis, dimension estimates were z-transformed per subject in order to compensate for individual biases. The rating results of each scene and category were averaged over all subjects. The linear correlation coefficient r was chosen as the basic statistical parameter, significance levels were calculated using Pearson's product moment correlation coefficient.

Figure 5.6: VisionStation$^{\mathrm{TM}}$ wide-angle spherical projection system as used in the experiment (images are based on pictures from the manufacturer's web site, see `http://www.elumens.com`).



(a) (b)

Figure 5.7: Effect of eyepoint height on relative distance estimate deviations. For proportional correctness, assuming that an estimated value half (deviation -100%) of the correct dimension (deviation 0%) is equivalent to a double overestimation (deviation +100%), the rating deviations are shown on a logarithmic scale to a base of 2.

Results. Strong significant correlations between eyepoint height and perceived egocentric distances were found (correlation coefficient r=-.51, p<.01, see Figure 5.7 right), as well as with allocentric distance estimates perpendicular to gaze direction (vertical r=-.35, p<.01, horizontal r=-.25, p<.01, see Figure 5.7 left). In contrast to that, allocentric distance estimates parallel to gaze direction did not show a significant linear trend. Regarding the correlations with rated experience, no significant interactions with eyepoint height were observable (explained variance r^2<.04). In contrast to the explicit dimension estimates, also the rated overall spaciousness appeared not to be affected by the experimental parameter. However, due to the small number of scenes the statistical power of this exploratory analysis was not very strong.

Discussion. The non-uniform effect of a varied eyeheight on distance and size estimates revealed considerable differences between different dimension and distance estimates, showing that different tasks are not directly comparable. This outcome may widely account for the partially differing results between studies in the literature. The most interesting result, however, may be the apparently different effects of the experimental parameter on egocentric distances in comparison to egocentric inter-object distances. This cannot be explained solely by affine compressions and may indicate that a shift of the vertical position might also change the perceived horizontal ego-location in VR. Informal observations of distance estimates in reality suggest that during this task mainly the floor surface between the standpoint and the target location is scanned visually. The higher the virtual eyepoint, the less floor is normally visible in VR (given that the vertical camera angle is fixed). Also, the cognitive framing theory as proposed by Psotka et al. (1998) predicates that the lower screen border is taken as the main reference for the ego-location. Together this would explain the observations, and implicate that a large vertical field of view could be a critical factor for virtual reality simulations aiming at conveying correct ego-location.

Conclusions. The experiment revealed significant influences of the virtual eyepoint height on the dimensional appearance of simulated architectural spaces. The results suggest that a lowered eyeheight in particular affects the accuracy of egocentric distances positively. Of course, there are practical limits for using this factor in architectural context. The useful variation range spans approximately from the height of furniture surfaces which are normally seen from above (approx. 1.20 m) to the pass line height of doors (approx. 2 m). Within these limits, virtual eyeheight offers a considerable potential to adjust the perception of dimensions and distances.

5.5.2 Horizon height

Introduction. The precedent study (Section 5.5.1) showed that the manipulation of a simple camera parameter considerably affects spatial perception in VR. However, the factor eyeheight has only a restricted useful variance range and is not capable of compensating all shortcomings of simulations alone. Thus, as a further easily influenceable simulation parameter, a subsequent empirical study (Franz et al., 2004a) investigated effects of manipulating the viewing frustum, mainly resulting in changes of the virtual horizon height.

Background. A frustum is a somewhat non-intuitive concept of 3D computer graphics for describing the projective characteristics of a central perspective on a flat projection plane by defining the limiting clipping distances of the viewport[2]. Unlike a camera pitch (which equally raises the horizon height), a frustum shift maintains the parallelism of vertical lines. It is well known in architectural photography that this is normally clearly preferable as long as a vertical perspective is not deliberately chosen as a means of artistic expression. Parallel verticals might be an important invariant for the interpretative perception of pictorial space.

Apparently, the vast majority of realtime computer graphic applications uses completely symmetrical frustums which results in identical viewing angles above and below the horizon. However, this arbitrary standard setting is in conflict with the physiognomy of the human visual system: Caused by the different overhang of forehead and cheeks, the visual field is vertically not symmetric to the horizon (see Figure 5.8). In combination with a usual slant of the neck (cf. Guski, 1996, pp. 75-83), this leads to a vertical shift of the visual center of about 24.5 degrees, and a dominance of about 2/3 to 1/3 of the visual field area below the horizon. Since humans often tend to overestimate the actual screen size in visual simulations (Schulte-Pelkum, Riecke, & von der Heyde, 2003; Schulte-Pelkum, Riecke, von der Heyde, & Bülthoff, 2004), it seems that this attentional focus of the visual field is cognitively zoomed to replace the whole visual field, as described by Psotka et al. (1998). Psotka derives from this that the lower boundary of the simulated visual field becomes the main reference line for the ego-location.

Furthermore, research in spatial vision has shown that the horizon conveys important information about the absolute scale and dimensions of environments (Sedgwick, 1973, 1986). This so-called angular declination depth cue (cf. e.g., Loomis, 2001) seems to be particularly important in monocular viewing conditions as often used in VR. Although there is obvious awareness of this perceptual factor in the VR community (cf. Stappers et al., 2003; Dixon et al., 2000; Wraga

[2]For more detailed information see Foley, van Dam, Feiner, & Hughes (1996, pp. 237-278) or Woo, Neider, Davis, & Shreiner (1997, pp. 124).

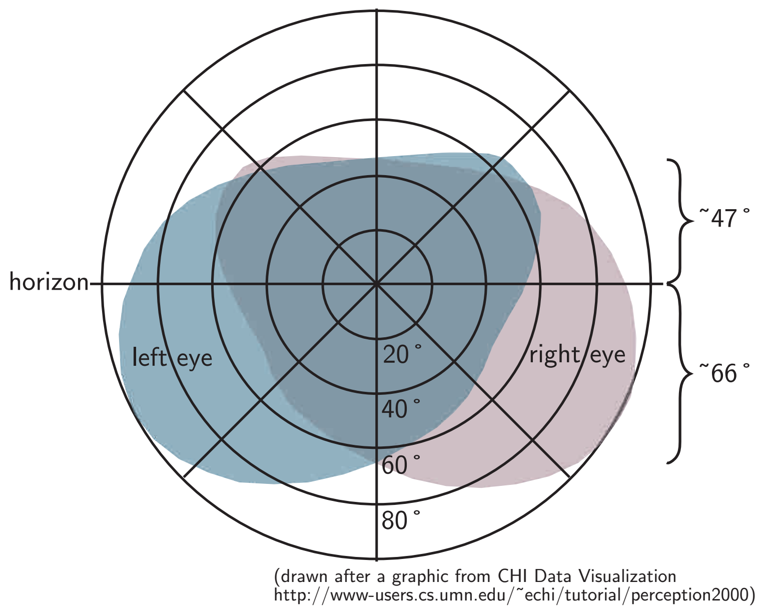


Figure 5.8: Sketch of the binocular human visual field. The exact form depends on the individual physiognomy of the face. On average, the vertical gaze center is about 24.5° below the horizon.

& Proffitt, 2000), it is surprising that apparently effects of changes of this corresponding simulation parameter have not yet been systematically investigated.

Objective. An empirical experiment was designed to investigate effects of manipulating the ratio between visual field below and above the horizon on the perception and experience of virtual architectural spaces. Due to the assumed relevance of the lower screen boundary as reference for the perceived virtual egolocation, it was expected that a raised horizon would particularly increase the length of perceived egocentric distances.

Method. Apart from the different manipulated independent variable *horizon height*, the experimental design corresponded to the study presented in Section 5.5.1. The main experimental parameter horizon height was switched from scene to scene to either 50%, 56.25%, 62.5% or 68.75% of the screen height (cf. Figure 5.9). The real eyeheight was fixed with a chin rest at normal seating height (about 1.20 m), the virtual eyeheight was constant at 1.60 m. As display device, a color-calibrated industry-standard flat 21" CRT monitor at a resolution of 1024x768 pixels was used. The simulated geometrical field of view (FOV) was 90° by a physical FOV of about 60° (40 cm screen width, 35 cm screen distance).

Results. No significant correlations between the experimental parameter and horizontal and vertical exocentric size estimates perpendicular to gaze direction were found (see Figure 5.10). In contrast to this, egocentric distance estimates were significantly correlated (correlation coefficient $r=0.16$, $p<.01$). With regard

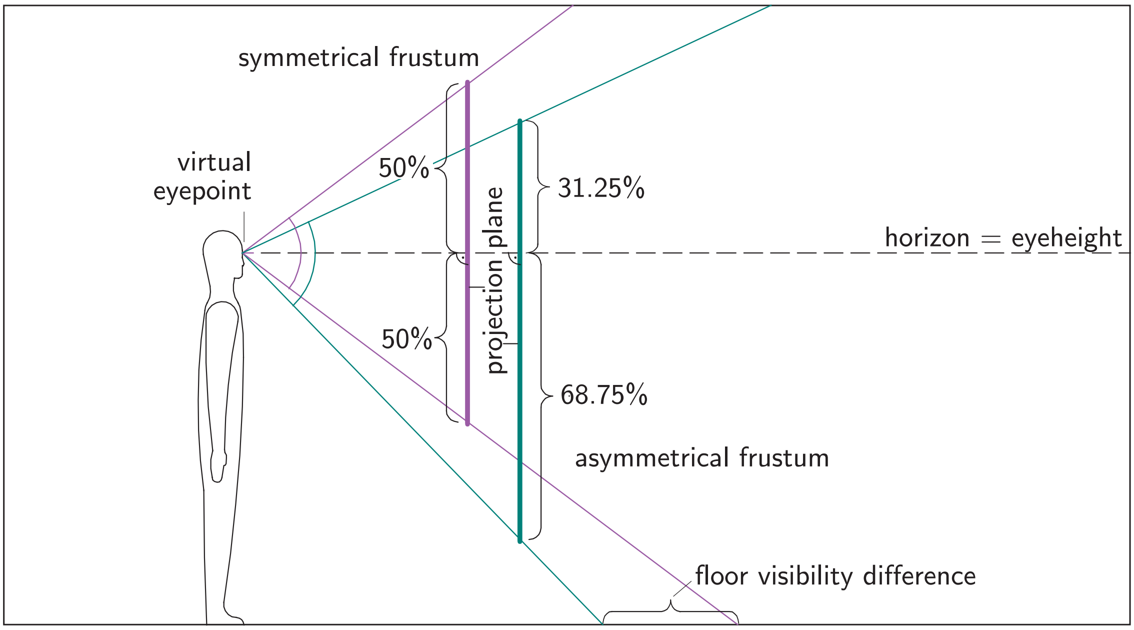
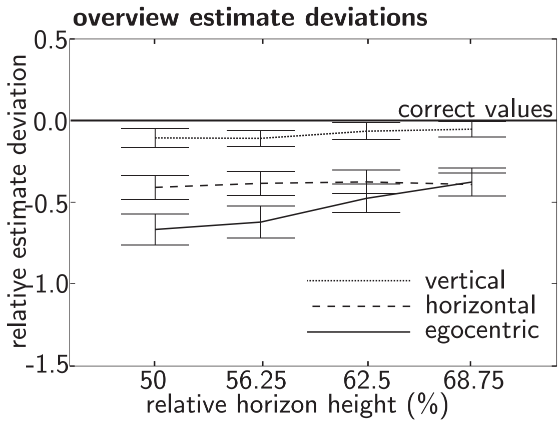


Figure 5.9: Sketch illustrating the effect of shifting the frustum towards the ground on the virtual visual field. It is apparent that more floor surface becomes visible, whilst vertical lines stay parallel. The figure shows the two extreme values of the geometrical field of vision that were used in the experiment. For better clarity the projection planes are displaced. The bounding box corresponds to a room of 5.00 m length and 2.75 m height.



(a)

Figure 5.10: Effect of frustum shift on distance and size estimates relative to actual values (corresponding to 0). For proportional correctness, assuming that an estimated value half (corresponds to -1.0) of the correct dimension is equivalent to a double overestimation (corresponds to +1.0), these rating deviations are shown on a logarithmic scale to a base of 2.

to the deviations in relation to the corresponding correct values, vertical dimensions were underestimated relatively least (average relative deviation approx. -10%). Whilst exocentric dimensions were constantly underestimated (average relative deviation approx. -40%), the underestimation of distances was reduced by 29% on average. Regarding affective appraisals, a non-significant correlation tendency between the experimental parameter and rated beauty (r=-.26, p=.15) and brightness (r=-.23) were observed . Apart from them, the general level of correlations was very low (explained variance r^2<.03).

The post-experiment questionnaire revealed an interesting detail of the phenomenal experience that can be attributed to the experimental parameter: While no participant was aware of the frustum manipulation, when explicitly asked, four of the eight subjects reported slight shifts of the virtual eyeheight (max. 30 cm) although this parameter was fixed. Altogether, the manipulation appeared to be fairly unobtrusive.

Discussion. The found main effect on egocentric distances is in accordance both with the cognitive framing theory (Psotka et al., 1998) and with the model of mandatory fusion of depth cues (e.g., Landy et al., 1995), because no participant became aware of the manipulation. The non-uniform effect of horizon height on exocentric dimensions and egocentric distance estimates revealed again strong qualitative differences between different distance estimate tasks. This generally observable independence has led some authors (Loomis, 1999; Brenner, Smeets, & Landy, 2001) to assume that different sorts of metric information are even represented differently in the brain.

The small potential influences on affective appraisals might be best explained by side effects: The negative correlation tendency (r=-0.23) between brightness and horizon height can be attributed to the actual reduced physical brightness of the visible scene that was more dominated by the darker floor. This could also be one factor contributing to the negative correlation (r=-0.26) with beauty, as beauty and brightness tend to be highly interrelated (e.g., see Section 7.2).

Conclusion. The study suggests that a raised horizon height is particularly suitable for improving the perceived ego-location in VR without negatively affecting other perceptual properties. At the virtual horizon height that matched the natural visual field best (about 66%), the differences between egocentric distances and horizontal dimensions vanished. For setups similar to normal desktop displays at least, this factor can be recommended as a practically applicable promising tweaking parameter. But also for immersive surround projections the potential of this factor for the vertical positioning of head-mounted displays or as tweaking variable should be considered.

5.5.3 Field of view (FOV)

Several studies analyzed effects of this parameter. Unfortunately, similar to the factors reported above, also these findings are difficult to compare directly, since they were obtained by using completely different setups and experimental tasks. A comprehensive investigation has not been done yet. So, the summary presented in this section is to some degree interpretative. Generally, two different aspects concerning the field of view (FOV) have to be discerned: the absolute size of the physical FOV and the proportion of simulated and physical FOV.

For differently sized physical FOVs, effects on distance and dimension estimates related to the cognitive framing theory of Psotka et al. (1998) can be expected (see Section 5.5.2). In other words, in particular influences on the perception of egocentric distances are probable, the depth dimension appears probably compressed in setups having small FOVs. In addition, Ruddle, Payne, & Jones (1999) reported negative effects of small FOVs on experienced presence. Also Schulte-Pelkum et al. (2004) investigated the effects of restricted FOVs on the perception of simulated ego-rotations. In contrast to Ruddle et al., they found that differences between display devices were more critical than the FOV for the perception of ego-rotations.

Regarding effects of a simulated FOV (also called geometric FOV) that deviates from the physical FOV, most authors agree that perceived dimensions and distances are to some degree a function of the ratio FOV_{sim} / FOV_{phys} (Waller, 1999, Dennis, 1999, in contrast to Arthur, 2000). From the geometry one could expect oppositional effects on egocentric distances compared to allocentric dimensions (cf. Ruddle et al., 1999). While, for example, an enlarged geometrical FOV adds more periphery to the visual field, including more floor surface, the central part gets compressed.

A rough estimate of the magnitude of effects of different physical FOVs on affective qualities can be obtained by comparing the studies of Franz et al. (2004b, 2005b) and Wiener & Franz (2005). Both experiments were based on the same set of spatial stimuli, but used different setups (VisionStation, FOV_{sim}= FOV_{phys}= 130°x90° versus standard CRTs, FOV_{sim}= 90°x67.5°, FOV_{phys}= 40°x30°). Since the ratings of both experiments were highly correlated, strong effects on ratings are rather improbable.

5.5.4 Freedom of movement and model quality

Although freedom of movement and model quality are, technically seen, two independent factors, in practice one often has to find a compromise between them, because visually-rich elaborate models that are illuminated using a physics-based lighting model can currently still only be reached with non-realtime computer graphics, implicating reduced interactivity. On the other hand, if free ego-motion and interactivity are key factors for a simulation, much simpler models and lighting techniques have to be accepted. Please note that in this section, freedom of movement is understood purely virtual, a combination with real physical ego-motion is discussed in Section 9.4.

Freedom of movement. Since motion parallax is an important monocular depth cue (Cutting & Vishton, 1995; Cutting, 1997), depth estimates probably become less reliable and get tendentially compressed in simulations having a fixed observation point. The empirical results reported in Section 5.4 are indeed in accordance with these predications. However, a comparison to the similar study of Henry (1992) that allowed for simulated ego-motion does not firmly corroborate this hypothesis, since his results are actually widely similar.

Christou & Bülthoff (1998, 1999) tested for effects of self-controlled ego-motion on the recognition of virtual scenes. They found positive influences of ego-motion on memorization and on extrapolation of novel perspectives. Bülthoff & Christou (1999) also found that virtual ego-motion helped in the recognition of object configurations. Wiener & Franz (2005) investigated the effects of restricting the freedom of movement on the experience of architectural spaces. For their particular scene set consisting of 16 indoor environments (cf. Section 7.4), they could not find any significant differences between the two conditions.

Model quality. Several different factors contribute to the overall impression of model quality, for example geometrical detail and accuracy of lighting. The relevance of these factors seems to be strongly task dependent. Concerning spatial perception and knowledge, the study of Willemsen & Gooch (2002) suggests that graphical quality is of secondary importance. Regarding affective qualities, however, findings on conventional simulation media (cf. Section 5.2) suggest a key importance of correctly rendered lighting and surface materials.

As a tentative summary of this section, one could say that the current state of knowledge suggests that obvious shortcomings of the discussed factors probably affect simulations less severely in most tasks than expectable. One can ascribe this to the ability of the human perceptual and cognitive systems to complete missing information unobtrusively in the most probable manner. On the other hand, an optimization of these pictorial parameters alone is probably not a viable way solve the scaling problems of VR simulations in general.

5.6 Practical economical considerations

In order to optimize the benefit of using simulations, it is of course preferable to minimize the preparatory effort while still keeping a high level of external validity in matters of the particular applications. Several virtual environment quality parameters are directly related to the necessary human effort to build the environment, for example the level of geometric detail of the model, the quality of lighting, and the elaboration of surface and material definitions (see Section 5.5.4).

Particularly empirical factor-analytic studies that use an experimental paradigm similar to psychophysics (see Section 3.5.2) need large sets of stimuli featuring completely controlled and balanced variations, goals which are almost impossible to achieve using real environments. Virtual scenes, on the other hand, provide the necessary flexibility, but their generation by hand is usually too labor-intensive for larger quantities. For each scene of the reported comparison study (Section 5.4), an experienced designer had to spend about one week for modeling and surface and lighting elaboration. Obviously, this is one apparent reason why the potential of VR is still only marginally used for scientific research. Additionally, conventional computer aided design (CAD) programs do normally not provide scene data in a useful format for further analysis. Hence, for several studies of this thesis project, the stimuli were generated in a widely automated process using a custom-made tool called SceneGen (Franz et al., 2003b).

SceneGen combines the good pictorial quality of photo textures and a physics-based radiosity lighting simulation with the complete and convenient control of a high level XML-based description language. Thus, both scene features and rendering parameters are parametrically adjustable, allowing for an automated generation of large numbers of 3D high-quality realtime OpenGL models or panoramic images with exactly defined differences. The process implicates a complete scene description that is directly available for further analysis. Together this facilitates a factor-analytic experimental design that goes beyond precedent mainly case study based approaches. Recent versions of SceneGen are capable of generating sets of scenes with equally distributed parameters, a feature that is very handy for psychophysics. Together with large scene sets, this reduces the risk that observed effects are merely artifacts due to coincidental trends in the scene set. The main limitations of SceneGen are currently the rudimentary user interface, and its restriction to rectangular forms.

5.7 Summing up

All in all, due to its flexibility and perceptual realism, VR appears to be a medium particularly suitable for architectural simulation. Sticking to Henry's framework, the results of several experiments testing its reliability in two of the architectural core requirements experiential qualities and the formation of configurational knowledge are altogether promising.

However, two limitations shall be clearly mentioned. First, due to the vast parameter space of VR, all empirical findings on the validity of simulations are by no means exhaustive, the current state of knowledge is far from being comprehensive. Subjectively, the most urgent fields for further research are the currently completely unknown relevance of multi-modality (mainly sound) for architectural simulations, and the quality of lighting models, since this factor currently still mainly determines the possible level of interactivity. Second, most studies report considerable differences between VR an reality concerning the perception of dimensions and distances, leaving the scale accuracy problem as a major unsolved issue. Yet, for the purpose of this dissertation, this drawback does not seem to decisively handicap the main goal of identifying physical correlates to affective qualities, since the compressions appear to qualitatively preserve the relations as a general bias, so comparison studies within one medium should not be affected.

One could generalize this point and say that absolute information is often not conveyed realistically by VR, yet the fidelity for rendering differences between scenes within one setup seems much more reliable. Hence, comparative experimental or simulation designs are currently clearly preferable. Finally, before beginning larger studies it seems worthwhile to calibrate a particular setup for example by simple preparatory studies replicating experiments reported in this chapter. This allows using the potential of easily adjustable simulation parameters to tweak the accuracy of the particular setup. Such pilot tests also facilitate the generalization of findings and the comparison to other studies.

Chapter 6

Affective qualities and physical properties

6.1 Introduction

This chapter briefly reviews both explanatory and predictive theories about relations between physical properties and affective responses to architecture or the environment in general. Currently, no existing theory can claim to be truly comprehensive. One reason for this might be that emotions as generic and integrative psychical responses may be elicited by various events, therefore a comprehensive theory of emotion would be more or less identical to theory of mind. It is doubtful whether such a generic theory would allow direct concrete architecture-related predications beyond commonplaces. Therefore, in any case individual theories that describe and at least partially rationalize specific patterns of relations are still worthwhile to be considered, because they offer a valuable basis for empirically testable concrete hypotheses. Yet before reviewing the more detailed theories mainly originating from architecture (Section 6.3) and environmental psychology (Section 6.4) , the following section coarsely outlines a more general picture by presenting some generic basic mechanisms individual theories may relate to.

6.2 Basic mechanisms

Emotions are immediate responses of an organism to a given situation within its environment (Schneider, 1990). Since emotions are a biologically based and therefore evolutionarily proved phenomenon, one can assume that they do not only have their triggers, but also serve distinct functions. Their primary biological relevance is seen in the immediate selection of behavior programs, they also regulate the intensity and duration of reactions. Furthermore, they are seen as strongly involved in memorization and learning (Killcross, 2000). That means, emotional responses influence the probability of memorization, and the semantic content is represented together with emotional connotations. For example, current models of territorial behavior use a simple value component in spatial memory in order to predict the probability of approach to a certain area (Basten, Schmolke, & Mallot, 2004). Furthermore, the function of emotion can be imagined as an internal reward system for behavior that is probably beneficial for an organism. The bases of these evaluations are seen phylogenetically (i.e. grounded in the evolutionary genesis of a species), leading to unconditioned responses, as well as based on individual prior experiences. The latter may partially explain the close relation between emotion and memory. Within this general framework, the individual predictive theories to be presented in this chapter may be integrated and summarized as follows:

27. Unconditioned responses to basic sensations: Individual factors light, color, temperature, sound, tactile, odor stimulation. Actual responses can be rationalized and predicted based on the usefulness of certain stimulus intensity ranges for perception, well-being, or action. See Sections 6.3.2 and 6.4.2.

28. Accompanying evaluation of the act of information processing. Two basic mechanisms are assumed: Short term effort and long term captivation. Aesthetic pleasure has been therefore explained as award for cognitive transfer (Leyton, 2001). See Section 6.4.3.

29. Evaluations within an action-context. Either appraisal of offered functions with respect to current plan (specific behavior, see Section 6.4.1), or evaluation of long-term general potential of interaction during diversive (exploratory) behavior. Also atavism: Preference patterns as evolutionary adaptations to environments and features advantageous for survival in prehistoric times. See Section 6.3.3.

30. Direct association of a place (cf. Section 2.2) with a former emotional experience (also called individual anecdotal meaning Manzo, 2003). This conditioned response is bound to the identity of a place, but rather independent of its physical structure. Hence, this factor is not further discussed within this dissertation.

31. Emotional value by reference: Perceptual or situational similarity or relation to affectively laden spaces or objects, or by purely culturally conveyed symbolic meaning (Lang, 1988). Analogies to archetypical experiences of

the womb or sexual stimuli (Westermann, 2001). Empathy: transfer of perceived forms on body posture or deformation (Bloomer & Moore, 1977; Weber, 2002). See Sections 6.3.1 and 6.3.2.

6.3 Architectural and aesthetic theory

According to Giedion (1941), since the Roman age at least, the design of interior space has become the most prominent issue of architectural design in Western architecture. Classic architectural tracts do not discuss problems of experience or affective qualities, but give detailed advice instead on how to practically design beautiful buildings, without reflecting much the phenomenon of beauty itself, which is taken as something objective. Within the framework of affective qualities introduced in Section 2.6, beauty can be seen a main constituent of the affective core dimension valence (see Chapter 2.2). While ideals of spatial form and configuration have changed over time from accurately defined to so called fluent spaces (Le Corbusier & Jeanneret, 1926), these shifts of paradigm have not questioned the primary importance of the issue of shaping indoor spaces. It is still the most prominent topic of textbooks on architectural design (e.g., Krier, 1989; Ching, 1996). However, applied systematic rules that relate spatial structure to experiential qualities are rare nowadays.

6.3.1 Proportion systems

Proportion rules are a method to choose different dimensions of a building in defined relations to each other. These recurring dimensions serve as a compositional link and are seen to strengthen the internal coherence between different parts. The importance of proportions has been argued theoretically from antiquity (Vitruvius Pollio, ca 25 BC) over the renaissance age (Alberti, 1485; Palladio, 1570) to the 20th century (Le Corbusier, 2003). There are innumerable built examples which follow proportion systems from almost every epoch and culture.

With regard to architectural indoor spaces, the theories of Andrea Palladio are particularly worth mentioning (summarized mainly after Wittkower, 1949). Influenced by Alberti, he transferred generic proportion rules to architectural space most consequently, finalizing a general tendency of Italian renaissance. His theoretical and practical work has been extraordinarily momentous for architectural history, Palladianism became a fixed term for a particular classicistic style. In the "Quattro Libri". Palladio (1570) gives a compilation of the "most beautiful space proportions" (Book I, Chapter XXI) and detailed rules on how to calculate the room height depending on the base area dimensions (Book I, Chapter XXIII). His main theoretical achievement is seen in clear specifications of how to relate structural parts to each other (e.g., proportion of windows to room size , Book I, Chapter XXV) and how to integrate whole spatial sequences and configurations into a general concept.

Classic authors seldom give further explanations for the reasons of the goodness of the proposed proportions, but a general foundation in Pythagorean numerology and cosmology is clearly obvious. In this context, good proportions in fine arts are seen as expression and correspondents to universal cosmic order principles which are most strikingly apparent in musical harmonies. Therefore, proportion rules are not only based on immediate perception, but also substantially normative. Yet it has to be considered that the final codified forms are the result of a long quasi-evolutionary development, a general characteristic of ancient building (Alexander, 1967) that is well documented in architectural history (e.g., Koch, 2003).

So, what is to say about proportion systems from a modern perspective? As early as 1876, Fechner investigated preferences for proportions of two-dimensional shapes by means of psychophysics. His results backed empirically the particular importance of the golden section for human aesthetic responses[1]. In addition, different theories have been raised that have a potential to support proportion rules by giving an explanation for their effectiveness: The application of proportion rules is seen as an effective means to increase the overall coherence of buildings, since they replace a complete arbitrariness of dimensions by a (possibly also arbitrary) system of relations. This may explain the apparent success of diverse proportion systems based on various ratios that were used over different times and cultures (cf. e.g., Naredi-Rainer, 1983) and are at first glance appear mutually exclusive. Furthermore, several proportions often recur in various natural, particularly living, structures. Since a preference for flourishing natural settings or human resembling forms has been assumed to exist due to evolutionary reasons (Hildebrand, 1999; Oberzaucher, 2001), a transfer of these potentially innate preferences on corresponding forms in general is probable. Finally, the preference for ratios near the golden section has been explained speculatively by arguments originating from information theory, as being the optimal relation between similarity and diversity (e.g., Smith, 2003). In conclusion, there are no reasons to consider proportion systems to be generally antiquated or obsolete, yet their dated

[1]For difficulties to reproduce Fechner's results, see Höge (2004). His findings suggest that the preference of certain proportions may be not really universal but much more context and object category specific.

normative foundation and speculative explanation demands for an update based on contemporary empirical methods.

6.3.2 Color and lighting

At the level of sensory functions, color and light cannot be seen independently. Actual visual sensations are always a coproduction of light color and intensity together with the reflectivity and hue of surfaces. Yet, perceptually, light and color are independent phenomena, the visual system uses several cues and mechanisms to disentangle them (Adelson, 2000; Zdravkovic & Gilchrist, 2001). Also from an architectural and analytical point of view the distinction between lighting (determining the temporal appearance) and color as persistent surface property is reasonable.

Emotional responses to color in architecture. The exploration of influences of colors on the human psyche has a long tradition (e.g., Goethe, 1810; Itten, 1961). Colors are seen to be generally affectively laden (Nemcsics, 1993). The origin of these emotional qualities is considered to be symbolical (mainly valence) as well as physiological. Besides single colors, in color theories color compositions and distributions are seen as particularly effective. Also deviations from the norm may be an important experiential dimension (Lang, 1988).

Despite a large body of respective text books and general literature (e.g., most comprehensively Nemcsics, 1993), it is difficult to subsume the current state of empirically backed knowledge on the influence of room colors on emotions. A current overview on studies predominantly from North America can be found in an article by Stone (2001). The traditional approach (e.g., see Nüchterlein, 2004, and further literature referred there) characterizes phenomenologically distinct color hues individually. As alternative, the following section aims at summarizing the current state of empirical and normative knowledge in continuous affective dimensions. For this purpose, the PAD framework of emotions (Mehrabian & Russell, 1974, see also Section 6 on page 97) is used used and color attributes from the literature are tentatively translated into continuous scales along the three emotional dimensions valence, arousal, and dominance. For example, characterizations such as “oppressive” or “lightweight” are interpreted as expressions of high, respectively low object dominance. This approach is motivated by obvious similarities between adjacent color hues in traditional compilations, and it also accounts for findings of an exploratory study (cf. Section 7.2) and practical analytic requirements.

The current state of knowledge mainly allows for hypotheses concerning the affective dimensions arousal and dominance (Figure 6.1). Generally, warm and saturated colors are seen as more arousing, while the dominance dimension corresponds to light-dark, both within and between color hues. These initially phenomenological observations are supported by physiological data (Küller, 2001). It is noteworthy that clear statements on the primary emotional dimension valence are more difficult. Positive relations between brightness and saturation, and valence have been reported (Mehrabian & Russell, 1974, pp. 56-59). Regarding color hues, there are on the one hand unclear rankings, on the other hand more complex theories dealing with color harmonies (Itten, 1961; Choo, 2004). Besides a positive correlation of the hue dimension uniform-polychrome with arousal (Küller, 2001), further influences are rather poorly empirically backed, mainly because of the almost infinite numbers of possible combinations, but also because of an assumed dependency on the color-bearing object category (Hansen, 2003) and on the culturally dependent symbolic meaning is assumed. Related to that, different effects of room colors concerning the surface (floor, walls, ceiling) are reported (Nüchterlein, 2004). Here one could subsume this to a tendency to prefer more dominant colors towards the ground, while less dominant ("less heavy") ceilings are preferred.

Lighting. Concerning the influence of light, architects are generally well aware of the outstanding importance of this factor for the atmosphere of rooms, and many built examples in particular of sacral architecture are sound evidence of the skillful use of light in any era. For the artificial lighting of indoor spaces, Flynn (1988) has convincingly detected three major qualitative experiential dimensions of illumination. In his framework he distinguishes between direct overhead light, indirect overhead light, and indirect peripheral illumination. However, systematic investigations of relations to affective qualities only marginally exist. Mehrabian & Russell (1974, p. 63) subsumed a few studies on the influence of the intensity level of lighting on pleasure and arousal. Coarsely, pleasure and arousal were positively correlated with the lighting level. Furthermore, Küller (2001) has resumed his research on the physiological effects of general lighting levels and quality. There is reliable empirical evidence for the influence of light on psychoactive hormones that affect, for example, activation levels over the diurnal or seasonal rhythm. La Garce (2004) tested for influences of different illuminations on Alzheimer patients. Positive effects of an illumination simulating daylight on patients' behavior were found.

6.3.3 Spatial form

Although spatial form is traditionally seen as the primary dimension of architecture (Giedion, 1941), little is known about the influences of spatial properties on

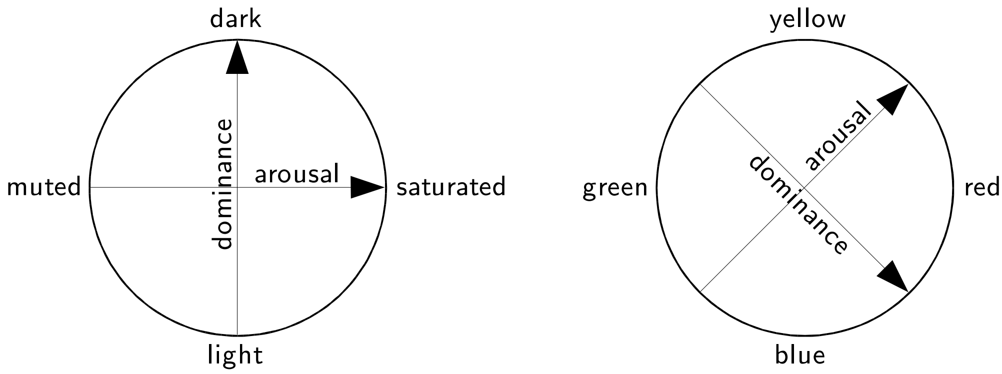


Figure 6.1: Conceptual relations between color properties and dimensions of emotion.

the affective experience of architecture beyond the mere fact, that they have an enormous emotional potential.

Density of space. In his outlined theory of architectural space, Joedicke (1985) considers the experience of architecture to be mainly subjective, implicating a lack of general patterns. Nevertheless, he points out that emotional qualities arise already from the primary spatial quality density (described in Section 4.2.3). For example, both very high and very low densities tend to be experienced as unpleasant. This quality is most obvious in the pathological extremes of claustrophobia and agoraphobia. The mood-altering capacity of spatial dimensions is also clearly apparent from basic adjectives describing spatial size that often have a strong emotional connotation (e.g. narrow, cramped, poky, spacious, ample, cf. Section 2.4).

Evolutionary theories. Formally related to density of space, the theories of "prospect and refuge" and "defensible space" suggest preference patterns for environments combining enclosure and openness. For example, Appleton (1988) proposed that, due to their evolution in the savannah[2], humans prefer environments that offer various cover and at the same time allow overlooking large other spaces. While this prospect and refuge theory was initially explicitly related to molar environments and not to single places, it has been often transferred on the analysis of rooms (e.g., Hildebrand, 1999). Similarly, Newman (1996) using the catchphrase "defensible space" has proposed specific design guidelines for architects that take similar aspects into account such as protected backs and easily controllable entrances. Besides influences on valence, mainly an increased experienced dominance can be assumed.

Scale. Regarding further influences of spatial form on the third emotional dimension dominance, at least common architectural practice suggests that an in-

[2]Although the savannah hypothesis appears according to current knowledge very doubtful, the general pattern of prospect and refuge seems not to be restricted to open grasslands.

creased scale and in particular large heights are effective means to increase the dominance of a building. Furthermore, neo-classicistic design conventions allow the interpretation that symmetries and repetitions also contribute to the experienced dominance of architecture.

Interaction between color and space. Besides their conceptual independence, normative knowledge provides for some rules of thumbs concerning the influence of colors on perceived room dimensions. Generally, cool, desaturated, and light colors are considered to increase the experienced spaciousness, whereas dark, saturated, and warm colors tendentially have opposite effects. These characterizations fit well to the sufficiently documented phenomenon of color perspective (e.g., Nemcsics, 1993): Since on the earth the atmosphere has the tendency to influence colors towards pale blue depending on the distance, color perspective is a reasonable relative depth cue for large-scale distances (Cutting & Vishton, 1995). Thus, also sensor integration models suggest such effects. Analogously, it is recommended to make extensive use of saturated dark only in large rooms (Nüchterlein, 2004).

All in all, the reported findings and theories on spatial form are still not sufficiently empirically backed and analyzed, for example their context dependency, transferability, and generality are mainly open questions. Finally, phenotypically oppositional space related psychoses such as claustrophobia and agoraphobia suggest that here the individual predisposition may play a substantial role regarding reactions to particular spaces.

6.3.4 Material and construction

It is common architectural practice to associate materials and constructions with certain qualities of expression. For example, (dark gray) steel is often used to convey a massive technical atmosphere, glass has the connotation of modernism and cleanness, wood is related to hominess, or stone to durability. It seems suggestive to ascribe such typical associations also an affective connotation. However, the author is not aware of systematic investigations or codified theories based on material or constructive properties. However, cross references can be outlined to several sections. Generally, many materials have a natural color, therefore characterizations described in Section 6.3.2 may be to a certain degree transferable. Similarly, different constructions normally lead to distinct patterns of spatial differentiation and lighting, so construction related factors may be partially captured in the Sections 6.3.2 and 6.3.3. In addition, emotional responses due to tactile perception (e.g., surface roughness and temperature) have to be considered (see Section 6.4.2).

6.3.5 Pattern language and related theories

Alexander's influential "Pattern Language" (1977) provides several specific design guidelines for the generation of spatial layouts and shapes. One core predication of the pattern language is that successful buildings cannot be conventionally designed but only originate from a generative process. For this, Alexander's books (Alexander, 1977, 2003a) provide a general guideline consisting of basic elements, the patterns, and a complex graph-like structure that connects the patterns in sequence, form, and content. The concept of patterns is nowhere completely defined by Alexander himself and can only be approximated (Donath, 1998), an often cited catchphrase describes it as "a solution to a problem in a context" (Shalloway & Trott, 2001, p. 74). In Alexander's theory, a building incorporating these patterns gains some deep quality that can only be compared to living organisms. In terms of his theory of life (Alexander, 2003b), it becomes something that is alive itself[3]. The quality of life is open to immediate experience and makes inhabitants or users feel perfectly at ease and more alive themselves. Translated to the terminology of this dissertation, one could say that a living building offers optimal affective qualities, a high level of valence.

While this approach claims to be strictly scientific, its holistic and almost cosmological perspective does not fit into conventional scholar categories. For example, an objective empirical analysis and evaluation of buildings according to design patterns seems contradictory, since it does not appear possible to take the processural quality of the generative process into account adequately. Alexander himself indeed prefers an intuitive and qualitative introspective evaluation technique of the final whole instead (Alexander, 2003b, p. 12).

However, there are partial theories related to Alexander's approach that fit well into the scope of relating affective qualities to measurable properties: Nikos Salingaros (1995) has proposed some laws to quantify or predict the perceptual quality or beauty of buildings from their structural properties. Related to concepts from information theory (cf. Section 6.4.3), he gives detailed advice on how to estimate a building's "temperature" and "harmony" by introspectively rating specified structural properties and features that are the basis for approximately calculating its complexity and "life" (Salingaros, 1997). The general approach has therefore some similarities with the entropy concept of Stamps (2002, 2003). Furthermore, he has developed a theory of the hierarchy of scales (Salingaros, 1998), which is similar to proportions but allows the calculation of an overall goodness value.

[3]The term "life" for inanimate things may easily appear esoteric. Yet it has considered that there is a mathematical theory of structures using this term to describe a certain state of complexity that is most efficiently conceived as a unity (cf. Chaitin, 1970).

Methodologically, the dependency of introspective ratings of structural properties may be seen as a drawback, however, it seems possible to overcome this limitation in principle, because similar characteristic values might be detectable automatically. Therefore, it is generally noteworthy that he provides actual formulas that lead to hard quantitative values. While this certainly makes his theories vulnerable, the possibility of an empirical test (his own test was only carried out by himself exemplarily and introspectively) and a potential successive refinement obviously makes his theories valuable.

6.4 Environmental psychology

General overview. The main goal of environmental psychology is the explanation of individual human behavior and experience in interdependency with the environment. Therefore, environmental psychology aims at an equal and comprehensive consideration of internal and external factors. Its historic roots are on the one hand integrative concepts of biology and anthropology (habitat, anthroposphere, going back to Haeckel's, 1866, concept of ecology), and on the other hand, a certain dissatisfaction with classic experimental psychology and its remoteness from everyday life. Within the discipline of environmental psychology, several schools and approaches can be discerned. According to Miller (1998), one main direction may be called "objectivistic". Here the initial focus lies on the analysis of the physical properties of environments using quantitative data. On the other hand, "subjectivistic" approaches rather analyze phenomenological entities qualitatively.

In comparison to other subdivisions of psychology, environmental psychology was most momentous in the 1970s and has since then experienced a relative stagnancy. This can be partially explained by the fact that several core issues have not yet been solved (cf. Miller, 1998, pp. 178-190). Due to the shear complexity of the almost holistic general approach (e.g., the simultaneous consideration of inner and outer states and the mutual dependency of environment and individual), truly comprehensive theories are still missing. Also quantification methods for both environment and psychological response still lack accuracy and universality. Therefore environmental psychology has often been characterized mainly as a certain perspective instead of a separate discipline (Kaminski, 1976).

Delimitation. As apparent from the previous paragraphs, the scope of environmental psychology substantially overlaps with the topic of this dissertation, indeed, this project can be widely attributed to this discipline. With respect of perspective and objective, however, substantial differences become apparent. Tendentially environmental psychology can be characterized as more centered on the mind, in search of a theory ideally explaining individual behavior. Thus, non-physical (e.g., situational, social, action-related, differential) factors are equally considered and investigated. Whereas the focus of this work abstracts from individual or situational parameters and concentrates on persistent effects attributable to identifiable properties of the environment. Likewise, to a lesser degree the generation of comprehensive theories is aimed at. The primary motivation is rather the gain of knowledge that might be practically applicable in the architectural design process. In sum, environmental psychology and this dissertation share the same core question of how the environment affects human behavior and their emotions, environmental psychology rather strives for on an explanation of the processes, this project concentrates on the identification of actual elicitors or predictors and their affective correlate.

6.4.1 Psychological field theory and successors.

A milestone of environmental psychology was Kurt Lewin's psychological field theory (Lewin, 1982) originally from the 1930s: In this framework, the individual is conceived as an integral part of its environment consisting of a field of valences, i. e. evaluated potentially action-relevant entities. Behavior most basically manifests itself in movements within the psychological field, in approach or avoidance of valences or in corresponding substitute responses. In theory behavior can be completely explained and predicted if all inner and outer valences are known. This fundamental relationship is expressed by the classic formula:

$$behavior = f(person,\ environment) \tag{6.1}$$

However, the divisions of this model have their weaknesses: Literally, the individual cannot be seen independently from the comprehensive concept of its environment, and the introduced function term is an integral part of the individual. Therefore, it becomes clear that the main intention of Lewin's framework was not the decomposition, but the emphasis of the almost holistic breadth of potentially relevant factors.

An important aspect of the psychological field theory is that the actual emotional response does not only depend on the somehow averaged valences of the current field, but also on the directions of the vectors that often may produce conflicting movement tendencies (e.g., appetence-appetence conflicts, induced by two spatially opposed attractors, or appetence-aversion conflicts, due to close attractors and distractors). Later research in this tradition concentrated on the identification of stable (social) environment-behavior patterns (so called behavior settings, see Barker, 1968) as well as on a stronger consideration of the action context (contrasting stimulus-oriented behavior) for perception, representation, and interpretation of the environment (cf. ecological action theory Kaminski, 1976, pp. 255-259) that determines the actually relevant aspects of an environment. Related to this context, Russell & Snodgrass (1987, p. 267) have assumed that the "the single most important environmental variable affecting mood and affective appraisal may be an environment's ability to fulfill the goal". While these theories are not environment-centered and do not allow an autonomous spatial analysis, they nevertheless have often been used for qualitative psychological research. As a big advantage, they offer explanations for observable individually differing behavior that other theories often do not account for.

6.4.2 Reactions to basic sensations

Mehrabian & Russell (1974) give an overview on relations between basic sensory responses and their three main dimensions of emotion (pleasure, arousal, and dominance). Pleasure (valence) is partially directly dependent and therefore predictable from basic physical properties such as brightness (cf. also Meier et al., 2004), temperature, moisture, and noise levels. Additionally, kinesthesis (body posture, movement comfort, e.g., the slope of stairs) and tactile perception (surface roughness, softness) belong to this category of factors. Finally, in several empirical studies Schira (2002) demonstrated relations between aesthetic preferences and pictorial frequency patterns of surface textures. Her analysis used mathematical models that resembled basic processes underlying early human vision (cf. Section 4.4.1), hence, a direct emotional response to a sensory reaction was hypothesized.

6.4.3 Information theory related concepts

Theoretical background. A group of theories (for an overview see Fisher et al., 1984; Gifford, 1997) relates affective responses to perception and information processing. The theories are based on the supposition that the act of information processing in the brain is accompanied by parallel emotional evaluations independent from the actual content, but that these emotions are attributed to the eliciting stimulus. Emotional arousal is seen as a direct correspondent to psychical work load induced by a stimulus. An information rate below a certain threshold or exceeding the processing capacity is negatively evaluated, whereas the coping with information amounts near the processing maximum is rewarded by positive emotions (Smith, 2003). Since these processes are conceived as independent from the semantic content, the structural properties of the information stream are central. For a further specification of abstract structural information properties, phenomenological correspondents (collative variables such as complexity, diversity, perceptual richness, order, legibility, clarity, and coherence, see also Section 2.5), as well as concepts from information theory (cf. Shannon, 1948) have been used (e.g., visual entropy). Despite some obvious affinities and correspondences, the exact definitions and delimitations of the various concepts however are often rather vague. All in all, there are strong indications for at least two main dimensions, that may be provisionally identified and termed as *complexity* (implicating diversity, entropy, richness) and *order* (comprising also legibility, clarity, coherence). In terms of information theory, complexity denotes the absolute amount of information (or rate if temporally seen), whereas order may signify the amount of higher-level structural information.

Empirical findings. While architectural theory tends to stress the aesthetic value of order that is rationalized by sustained perceptual interest (Weber, 1995, pp. 121-129), psychological experiments have rather concentrated on the effects of complexity. First Birkhoff (1933) introduced a formula that claimed to allow the calculation of the beauty of a shape as a quotient of its order and complexity that were directly determined by measurable properties such as the number of vertices of its outline (Staudek, 1999). In his seminal works Berlyne (1960, 1972) provided a stable theoretical basis and introduced the often-cited inverted U-shaped curve as conceptual relation between elicited arousal and pleasingness, that were predicted by introspective ratings of the complexity of stimuli. Later Oostendorp & Berlyne (1988) diversified the introspective physical rating dimensions and demonstrated correlations between several detail properties of building exteriors (e.g., amount of ornament, roundness, dominant directions) and aesthetic preference. Nasar (1988a) reported results for outdoor environments of residential areas that fit well to the order and complexity framework. Furthermore, a similar approach was used for the analysis of complete residential areas (Nasar, 1988b; Klockhaus, 1976; Rothgang, 1976). Lozano (1988) introduced valuable differentiations between evaluations of a current stimulus array and preferences for complete environments that seem useful to integrate partially contradictory results regarding diversity and complexity. Criticizing the approach of comparing introspective collative variables with introspective emotional variables, Stamps (2000, p. 51) made use of computer-based quantitative analyses of building facades, and later (Stamps, 2002, 2003) introduced the concept of visual entropy as physically measurable predictor for environmental diversity, and thereby arousal and pleasure. Within the range of entropy tested (0 to 5.6 bits), linear relations between entropy and pleasure for building facades were found. However, since the kind of stimulus strongly restricts the range of entropy, the empirical results do not generally disprove Berlyne's theoretically derived inverted U function.

Taken together, information rate based theories suggest that pleasure is tendentially highest in stimuli or environments that combine high levels of both complexity and order.

Predictability. Closely related to these static collative stimulus properties are concepts that relate to the *predictability* of an environment (e.g., clarity, or Mehrabian & Russell's "novelty" and "uncertainty" as part of information rate, 1974, pp. 75-97). Also the "mystery" theory (Kaplan, 1988a) suggests increased arousal and pleasure by environments promising new information when moving further. In addition to the effects on arousal and preferences for certain "optimal" levels of predictability, a very direct influence on dominance can be assumed. Actual predictions based on the factor predictability seem however difficult, since its influence strongly depends on non-physical factors such as previous exposure and familiarity. Furthermore, the relation between valence and predictability seems also to be situationally dependent. This becomes obvious in apparently contradictory predications that can be made upon the mystery theory and the defensible space theory (see Section 6.3.3) for the same spatial configurations. Therefore, the mystery theory appears to be most appropriate for diversive behavior like free exploration. In this case a positive effect on pleasure and arousal can be expected.

6.5 Summing up

Numerous theories and empirical studies deal with relations between affective responses and physical properties of the outside world, they offer various valuable hypotheses and individual findings. The current state of knowledge, however, makes it difficult to generalize them and to transfer them on practical design decisions (Lang, 1987). Therefore, deficiencies exist rather with respect of integrative theories and comprehensive comparative quantitative studies. Also, in particular factor-analytic studies on affective responses specific to architectural indoor spaces are comparatively rare. The empirical studies presented in the following chapter addressed the outlined shortcomings; several generic description systems for architectural indoor spaces were explored and analyzed on characteristic values that are systematically correlated with affective responses. The overall implications of these findings on the state of theoretical knowledge is then discussed in Chapter 8.

Chapter 7

Exploratory studies

7.1 Introduction

This chapter presents the central experiments of this dissertation. As outlined in the introduction (Chapter 1), besides a proof of concept of the empirical investigability of affective qualities, the primary goals were the identification of likely relevant single factors and a test of the capabilities of selected description systems to statistically explain variance in affective appraisals. Additionally, the experiments offered the opportunity to investigate exemplarily specific hypotheses derived from theories reviewed in Chapter 6.

Based on models and approaches presented in Chapter 4, three distinctive description systems were developed. The selection and development of these description models was on the one hand guided by the aim to cover a wide range of different factors. Yet on the other hand it was essentially an iterative process responding to previous results: The image-based study (Section 7.2) was initially a broad exploration of diverse sources of variance (e.g., also group-specific and gender differences) observable in affective appraisals. The basic image analysis was chosen due to its few prerequisites and relative simplicity. The stimuli could be obtained via internet search and offered already the data basis for the correlation analysis. Fortunately, the pilot experiment clearly supported the general approach and provided strong indications on a few basic yet apparently powerful predictor variables. Since these variables were mainly related to surface and lighting properties, the subsequent study (Section 7.3) concentrated on spatial properties and architectural features that were not captured by the basic image descriptors. To avoid the major difficulty of quantitatively describing spatial form and topology, the stimulus geometry was restricted to the most widespread rectangular forms. To overcome this formal limitation, the following experiment

(Section 7.4) specifically addressed the topic of finding generic descriptors of spatial form that capture emotion-affecting properties of architectural indoor spaces. Finally, the experiment described in Section 7.5 aimed at an exemplary integration of the previously independently investigated factors and on a direct empirical comparison of the description systems. A further more qualitative and interpretative comparison of the approaches is then given in the following chapter.

7.2 Study 1 - an image-based approach

7.2.1 Overview

The study described in this section was the empirical starting point of this thesis project and explored the general methodology of quantitatively comparing affective appraisals to external factors potentially affecting emotional responses to architecture. This first exploration covered physical factors as well as non-physical differential factors. The experiment was a web-based semantic differential rating in 12 categories of initially 15 photographs of architectural spaces. The test for relations to physical properties was based on image analysis. Several strong correlations between basic characteristic values describing color, brightness, and image edges on the one hand, and affective appraisals on the other were found. Later more advanced analyses explored the suitability of pictorial frequencies as predictor variables for experiential qualities and identified image features that were correlated with basic spatial characteristics of the scenes. Altogether, this initial study clearly supported the general approach of systematically comparing physical properties and affective qualities.

7.2.2 Introduction

In everyday life, photographs play an important role to convey information or general impressions of things, people, events, natural phenomena, and last but not least architecture. Contemporary humans are very used to photographic reproductions and normally estimate themselves as able to infer much about the depicted situations from a single snapshot. Indeed, photographs can contain an overwhelming amount of information spanning a wide variety of aspects of architectural environments, for example the materials and colors of surfaces, lighting conditions, furnishing, but also spatial properties and the surrounding context is often directly visible. While humans are normally capable of perceiving and interpreting visual scenes almost immediately and widely effortless, the extraordinary complexity of this task became really apparent as recently as people tried to equip machines with optical sensors. Still attempts to implement a powerful and flexible visual system are in premature stages. Therefore, on the one hand it appears extremely complicated to access a major share of the detail information contained in photographs. On the other hand, it is surprising how much and apparently relevant information can be obtained by a few basic computer-based analysis techniques. The combination of a digital camera and a consumer-grade image editing program already allows to obtain various single measurands, and a little bit more advanced programmable image-processing software allows to do efficiently statistics on large series of images.

The study described in this section made use of easily obtainable and manageable digital photographs for conveying impressions of architectural indoor spaces to participants as well as for the derivation of basic characteristic values from the scenes. A correlation analysis compared ratings of affective qualities of the scenes to differential data of the participants and the image-based descriptors of the scenes; already a few easily obtainable measurands were able to explain a major proportion of the variance in the ratings.

7.2.3 Background

This preliminary study was based on analyses of digital images and made use of basic methods of computer vision. Although the actual measurands mainly mirrored the underlying data structures, the whole approach of using a camera analogy for human vision and relating basic features directly to affective responses can at least be called biologically inspired.

At the level of retinal sensations, the human visual system has several analogies to a digital camera. Similar to a customary RGB sensor, different receptor cells are tuned to particular sections of the light spectrum and translate intensity values into firing rates. Furthermore, the eye accomplishes a compression of the vast dynamic range of natural light with a superior yet similar mechanism to the aperture of a camera. However, already at the retinal level the first stages of image filtering and enhancement occur as starting point of a multi-level information processing chain that subsequently extracts higher levels of features. While early models rather stressed the sequential and specialized bottom-up structure, more recent findings have shown that at the same time top-down influences are active, in fact, vision must be seen as a highly integrated complex process.

Despite this complexity at the neurophysiological level, recent findings in empirical and computational scene and object recognition research have shown that relatively few generic pictorial features are widely sufficient for recognizing scenes using a strict bottom-up approach (e.g., Bülthoff & Edelman, 1992). Humans accomplish such tasks in fractions of a second, even before conscious awareness (Thorpe, Fize, & Marlot, 1996). Torralba & Sinha (2001) and Oliva & Torralba (2001) have demonstrated how to effectively implement such to some degree biomimetic approaches in functional computer models that do very well in recognizing the scene category (see also Section 4.4.1) in similar dimensions as humans do. For example, early vision processing in brain area V1 has some similarities to Fourier analysis. In this area cells have been detected that are particularly sensitive for certain frequency ranges and directions. Furthermore, the reduced spatial resolution of analyzed stimuli corresponds to peripheral vision that conveys only a coarse impression of widely colorless patterns of light and dark values. It is well known that the perception and recognition process is simultaneously accompanied by emotional responses (cf. Damasio, 1997). Since almost the same experiential dimensions as detected by Oliva & Torralba (2001) are proposed to underlie affective aesthetic responses (Fenton, 1988), one basic assumption of this study was that the perceptual gist that allows for scene recognition may also contain primary factors influencing the emotional experience.

A methodologically related approach was taken byStamps (2000, pp. 49-52) who conducted a study on preferences of building facades. Similarly, affective appraisals were compared to measurands derived from digital images. Strong correlations with introspective impressions of visual richness and pleasingness were found. However, instead of applying directly extractable low-level image statistics, he rather followed earlier studies based on analog photographs (e.g., Oostendorp & Berlyne, 1988) and used more high-level semantic measurands such as the fraction of facade area that was covered by ornament, which had to be evaluated manually. Furthermore, in several empirical studies Schira (2002) demonstrated relations between aesthetic preferences and pictorial frequency patterns of surface textures. It can be hypothesized that similar visual patterns occur in architectural environments and potentially already induce certain tendencies in affective responses.

7.2.4 Objective

The primary goal of the study was a tentative quantification of assumed relations between affective appraisals and measurable pictorial features of architectural interiors. Since its purpose with respect to the overall thesis was mainly to gain a rough estimation of the feasibility of the general project, the study initially concentrated on a few global pictorial properties that were easily obtainable using basic image analysis. Nevertheless, several theories and studies reported in the literature suggested that already these basic measurands capturing global color, lighting level, and amount of detail could correspond to relevant factors influencing the affective qualities (cf. Section 6.3.2). In case of success of this initial exploration, it was intended to extend the analysis to more elaborate image processing techniques that implement further aspects analogous to early human vision (cf. Section 4.4.1). This second stage was again inspired by theories that suggested relations between pictorial frequency properties and affective qualities (see Section 6.4.2).

Furthermore, as first exploratory study of this dissertation project, the experiment served additional methodological purposes: The data raising method of the semantic differential for quantifying affective appraisals should be tested in general, and relations between different rating categories derived from a previous survey (see Section 2.4) should be evaluated. Also the level of communality between participants was of particular interest. For this reason, group-specific differences between participants having an educational background in architectural design and laypersons were analyzed. If such differences became apparent, they would offer an additional rationale for the whole project. In this case it could be argued that architects should not take their personal conceptions as valid models for the general public, and the development of a methodology to raise respective quantitative data should be of particular interest for them.

7.2.5 Method

Setup. The experiment design was similar to a standard environmental psychology paper-and-pencil test, except of the translation into a web experiment (Figure 7.1). Some advantages over the traditional method were expected: First of all, the electronic medium offered the potential to reach a broader audience easily. Second, digital presentation facilitated the complete randomization of the scene and rating category order. And third, a distribution of the experiment over many different computers allowed to neglect potential side effects caused by inaccurately calibrated monitor devices.

Task. The experimental task was a semantic-differential like rating of architectural photographs. The stimulus scenes were collected from architectural internet forums[1] and subjectively selected in order to maximize diversity. They comprised architecture from historic times to avantgarde and various functional categories. The rating was done in 12 categories on nine step Likert scales. Each

[1]mainly from architecture week `http://www.architectureweek.com` and Baunetz `http://www.baunetz.de/arch/`.

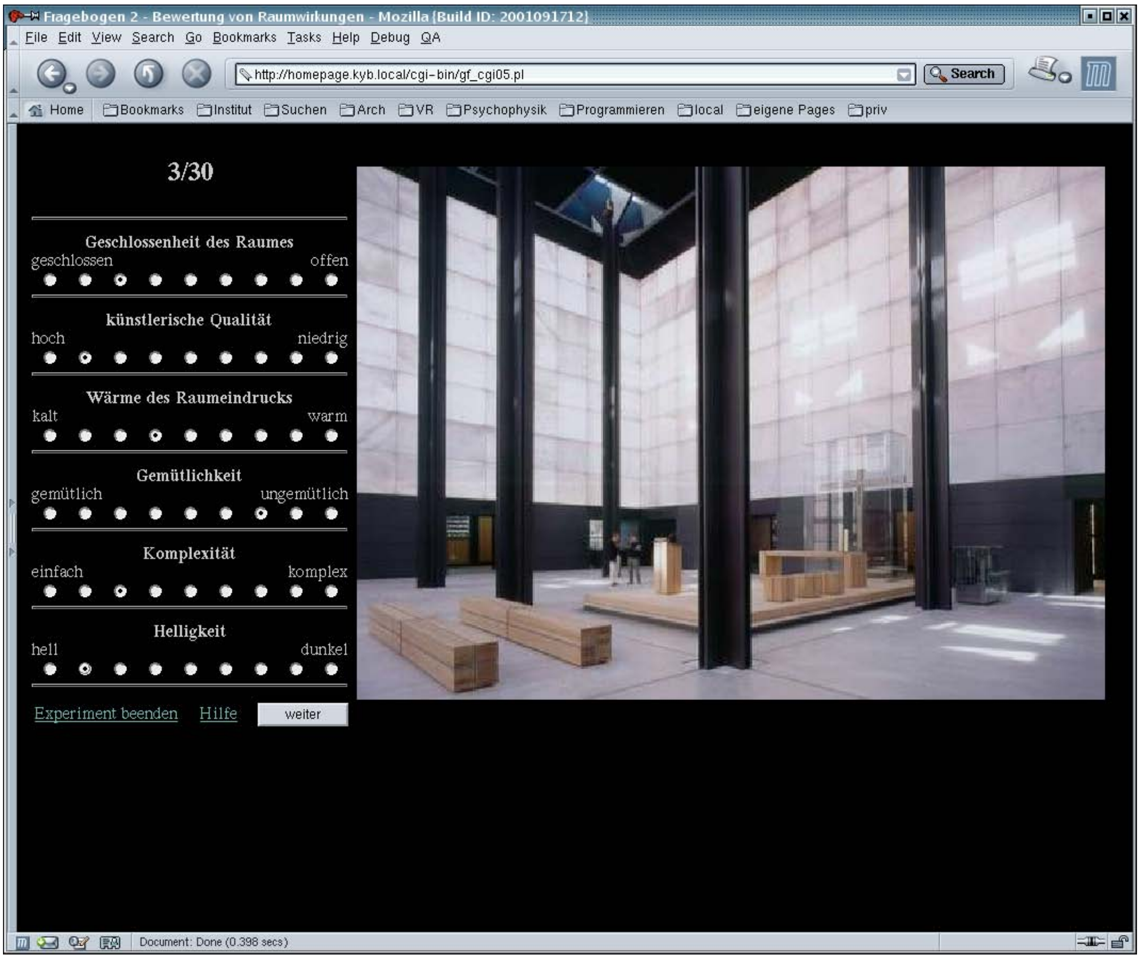


Figure 7.1: Screenshot of the web questionnaire.

Category in English	Category in German	German adjective I	German adjective II
comfort	Gemütlichkeit	ungemütlich	gemütlich
privacy	Privatheit	öffentlich	privat
rate of enclosure	Geschlossenheit des Raumes	offen	geschlossen
aesthetic quality	künstlerische Qualität	niedrig	hoch
warmth	Wärme des Raumeindrucks	kalt	warm
complexity	Komplexität	einfach	komplex
clarity	Übersichtlichkeit	unübersichtlich	übersichtlich
spaciousness	Angemessenheit der Raumgröße	beengt	großzügig
brightness	Helligkeit	dunkel	hell
personal appreciation	persönliche Wertung	negativ	positiv
simplicity	Schlichtheit	überladen	karg
dynamics	Bewegtheit	statisch	dynamisch

Table 7.1: The rating categories and pairs of oppositional adjectives used in Study 1. The experiment was conducted in German language.

rating category was represented by a superordinate term and a pair of oppositional adjectives (see Table 7.1). The selected rating categories represented the most mentioned categories in a preceding survey (cf. Section 2.4). The rating categories were complemented by further terms from architectural and art theory (complexity, dynamics). Due to the subjects' background, the experiment was conducted in German language.

Procedure. Before doing the ratings participants were informed in detail about the handling and the purpose of the experiment via introductory web pages. Then they were asked for differential data about their age, gender, and professional background. The filling out of these forms was voluntary and no prerequisite for participating. Afterwards they were shown digital photographs of 15 architectural indoor scenes in random order. Subjects could terminate an experimental session at any time, yet only completed evaluations of individual scenes were entered in the statistical analysis. A complete experimental session took about 35 minutes.

Participants. The first session was conducted with altogether 44 participants, 15 females and 29 males. There were two different groups, 11 (6 f, 5 m) subjects with a professional background related to architectural design (further called "architects") and 33 (9 f, 24 m) without (further called "laypersons"). The scenes of the second session was rated by 41 subjects altogether of whom 18 were female and 22 male.

Scene descriptors. In the initial analysis, the global color and lighting of the scenes were described by mean values, standard deviations, and relative proportions of different color channels in different color spaces (gray values, RGB, HSV, YIQ, and L$\alpha\beta$).[2] Furthermore, values describing image edges were calculated. For getting global values on the relative amount of edges, reduced resolution versions of the original images were filtered by a standard Laplacian-of-Gaussian (log) edge detection algorithm. The proportion between horizontal and vertical edges was calculated using a direction-sensitive Prewitt filter. The image analysis was performed using the Matlab® Image Processing Toolbox and the GNU Octave mathematical software package (`http://www.octave.org`).

The later detailed frequency analysis was initially done in all three L$\alpha\beta$ color dimensions. For this all scenes were cropped and rescaled to 256x256 pixels. Then a fast Fourier transformation (FFT) was applied to these images. The irrational component was discarded, and the remaining absolute rational parts were logarithmed. For the subsequent multivariate linear regression, several averaged very low resolution versions of the initial frequency matrices were generated. In order to further reduce the number of features, and thereby probability of overfitting the model, additional folding steps accounting for the symmetries in the Fourier matrices were applied. Based on these sets of characteristic values, multivariate linear regression models were computed using the following standard formula:

$$\vec{a} = (F^T F)^{-1} F^T \vec{y} \tag{7.1}$$

The complete procedure is schematically illustrated in Figure 7.2.

Analysis. The analysis tested for correlations between scene descriptors and mean ratings that were averaged over each participant group. For all statistical analyses the rating data was treated as even interval scaled. Correlation coefficients were calculated using linear Pearson's product moment correlation. Further statistical values such as significance levels, confidence intervals, or power values were not calculated due to the completely exploratory character of the

[2]The scene descriptors are further described in Appendix A.1.

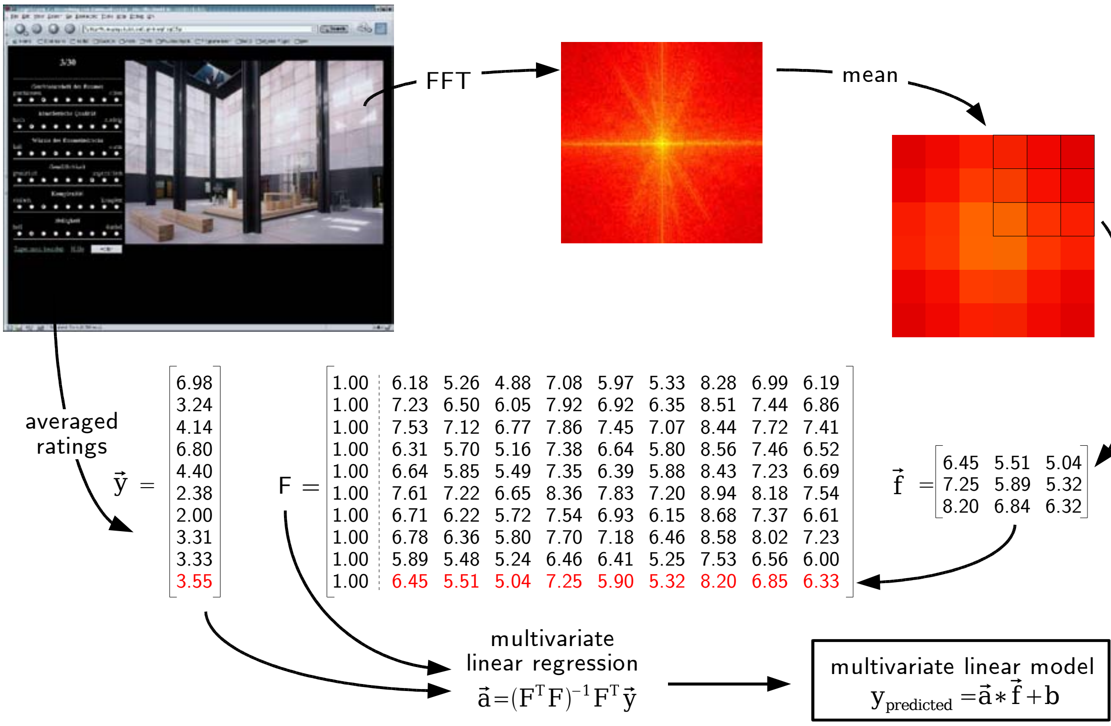


Figure 7.2: Schematic overview on the generation of the multivariate linear model using pictorial frequencies. The matrix F contains the measured image features (columns) for all test scenes (rows) and a constant column of ones. Vector $\vec{y}$ holds the corresponding averaged rating results of one category.

study. Furthermore, it has to be clearly stated that this experiment also served as the author's first testing ground and learning example for statistics, analysis methods, and experimental design in general. The initial basic analysis comprised only the 15 scenes of the first session. The later frequency analysis was based one data obtained by two independent sessions together comprising 30 scenes.

The predictive power of the frequency-based multivariate linear models of the later analysis stage was tested using a leave-one-out strategy: For each scene the averaged ratings were predicted by all other scenes of the test sample. These predictions were evaluated by two measurands: First, the accuracy of the prediction was measured by the absolute deviations of the predicted values from the rated value. Additionally, the correctness of the general tendency was quantified by correct predictions of the deviation direction from the mean.

7.2.6 Results

General. The obvious differences between the scenes were reflected by clear differences between the averaged rating data. The variance differed between the

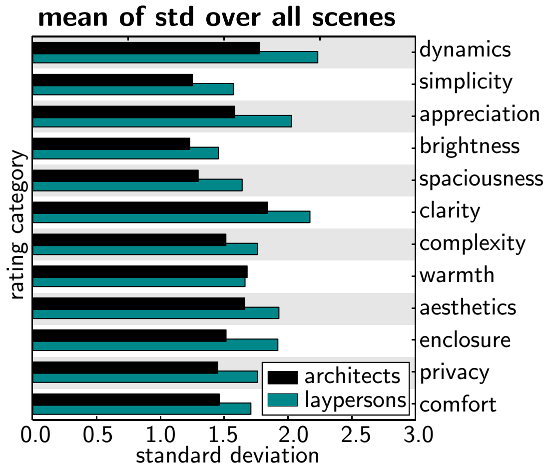


Figure 7.3: Mean of standard deviation over all scenes, itemized by rating category and group.

rating categories, the range of the standard deviation was from 1.4 to 2.2 at an equal distribution level of 2.74 for a nine step scale, indicating meaningful and unimodal mean values. Rated brightness, simplicity, and spaciousness showed the lowest variance; judgments on dynamics, clarity and personal appreciation differed most (Figure 7.3).

Several rating categories turned out to be interrelated. A group of categories became apparent that, in analogy to similar observations (e.g., Osgood et al., 1957; Heise, 1970; Mehrabian & Russell, 1974) could be interpreted as valence: comfort was very strongly correlated with rated warmth (correlation coefficient r=.90) and appreciation (r=.77). Therefore, in most analyses these three categories shared the same tendencies. Additionally, the rating dimension privacy (which would be rather related to the affective dimension of dominance) was considerably correlated to these categories. Second, several denotative physics-related rating categories widely coincided: The experienced rate of enclosure was strongly negatively correlated with rated brightness and spaciousness (both r=-.80). Furthermore, a third cluster of categories describing structural properties became apparent: Rated simplicity was negatively correlated with dynamics (r=-.70) and complexity (r=-.80). Since the simplicity ratings of laypersons showed a considerably lower level of variance (cf. Figure 7.3), this category appeared to be most suitable for further studies interested in capturing this experiential dimension.

Group specific differences. The differential analysis was performed only on the first scene set, because too few architects participated in the second stage. Overall, the responses of architects were slightly more consistent than those of laypersons: their standard deviation was 0.3 lower on average (cf. Figure 7.3). Furthermore, expected differences between the groups became clearly obvious:

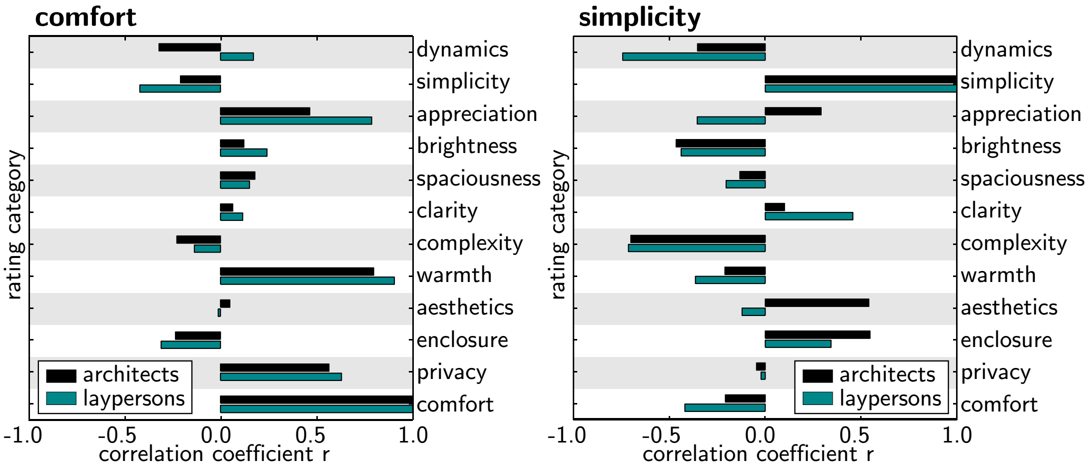


Figure 7.4: Plots exemplarily showing intercorrelations with the rating categories comfort and simplicity

For architects the concepts of simplicity and aesthetic quality were clearly positively (r=.55) correlated, whereas lay people showed a neutral or even negative tendency (r=-.10). The same relative difference (architects r=.30, laypersons r=-.35) with shifted absolute values was identifiable between personal appreciation and simplicity. This may also be the reason why complex scenes with more edges tended to be more positively rated by laypersons than by architects. Furthermore, there was also a large difference between the correlations of enclosure and valence related rating categories (appreciation / aesthetics). The ratings of laypersons showed a correlation coefficient that were about 0.7 lower than architects' ratings. Finally, it is worth mentioning that for architects aesthetic quality was much more related to personal appreciation than for laypersons (r=.85 / r=.45). This could be interpreted as such that architects internalized the code of current architectural aesthetics much more. All in all, the results fit well into the assumed preference of architects for more straight designs and contemporary avant-garde architecture (e.g., Wilson, 1996; Stamps, 2000, pp. 114-139). Apart from that, the level of intersubjectivity between the groups was fairly high. An additional evaluation of gender differences only found comparatively small differences that were assumed to be irrelevant.

Correlations with basic image properties. Most prominently, a very high correlation between the relative proportion of RGB red and the rated warmth of the scenes (r=.85) was detected. Similarly, this measurand was considerably correlated with privacy (r=.55) and comfort (r=.55). The correlations of the RGB green and blue proportions were widely opposite to red, and very similar to each other. A further color analysis using the psychophysically more correct L$\alpha\beta$ α and β dimensions did not explain additional variance. From the brightness re-

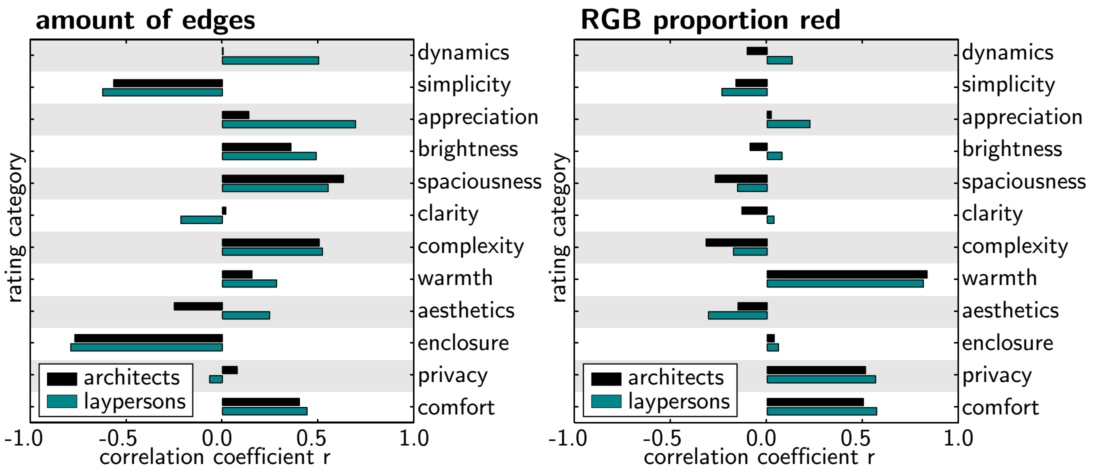


Figure 7.5: Correlations between ratings and selected basic image properties.

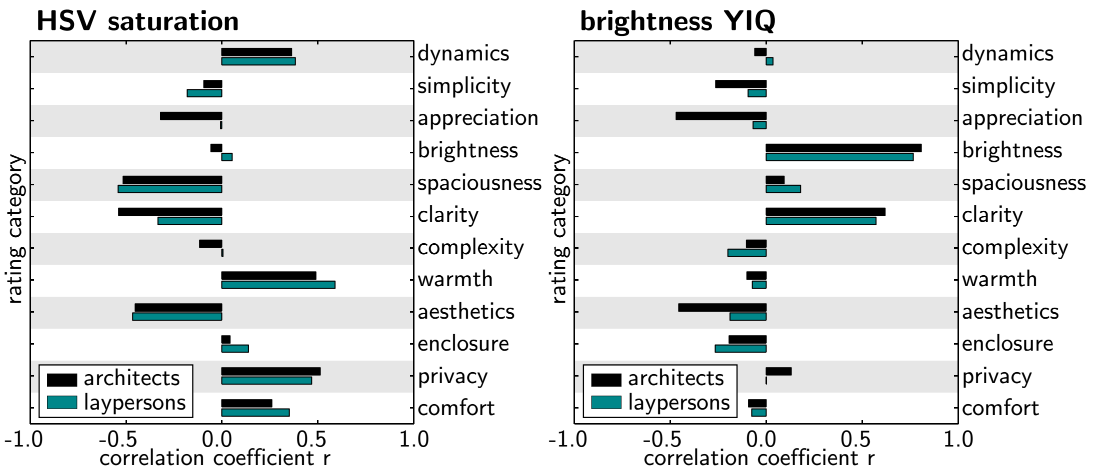


Figure 7.6: Correlations between ratings and selected basic image properties.

lated measurands the YIQ Y and L$\alpha\beta$ L rendered identical results. Both measurands fairly (r=.80) covaried with rated brightness, there was also a high correlation with rated clarity (r=.60). Also, several notable correlations with the amount of detected edges could be observed: Most prominently, rated enclosure (r=-.80) and simplicity (r=-.65) were strongly negatively correlated to that factor. Additionally, scenes with more edges tended to be rated larger (r=.60), more complex (r=.50) and were more appreciated at least by laypersons (r=.70, in contrast to architects r=.10). Finally, scenes with more saturated colors (HSV S component) were rated to be tendentially more warmer (r=.60), more comfortable (r=.50), but less spacious (r=-.60) and less aesthetic (r=-.50).

Results frequency analysis. At first glance the frequency analysis comprising both experimental stages rendered discriminatory and specific frequency patterns for most rating categories (see Figure 7.7), at least for the L$\alpha\beta$ L (i.e. lumi-

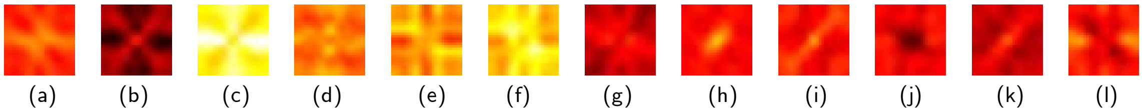


Figure 7.7: Correlations between global pictorial image frequencies and ratings: (a) appreciation, (b) enclosure, (c) spaciousness, (d) brightness, (e) dynamics, (f) complexity, (g) aesthetics, (h) hominess, (i) privacy, (j) simplicity, (k) warmth, (l) clarity.

nance) color component. For the α and β components, only global parallel trends for all frequency bands in any of the twelve rating categories could be observed that qualitatively corresponded to the warm/cold color dimension (e.g., relative proportion RGB red). Surprisingly, color hue appeared to be a global feature in this sample. Hence, further analyses concentrated on the luminance dimension. Since the significance levels of the single correlations also for the luminance component were tendentially low, for a further analysis an integrated multivariate model was chosen.

Test / comparison of models. The models based on a different numbers of features were compared by the absolute deviation of their predictions from the rated values (see Figure 7.2), and by the correctness of the tendential direction. Both measurands revealed identical findings: Solely ratings in experiential categories describing spatial characteristics were correlated with some very low resolution models comprising between two and six features. The only significant correlations were found to spaciousness (r=.39, p=.03) and enclosure (r=.42, p=.02), both categories were highly interrelated (r=-.80, p<.001). An additional test exclusively against the averaged ratings of non-architects yielded an almost identical result, indicating that the results were not just obscured by the pooling of the groups.

7.2.7 Discussion

Basic analysis. Generally, the high correlations between basic pictorial measurands and affective appraisals are a strong support for the initial hypothesis that there are systematic relations between physical properties and affective responses to architecture. Beyond that, the detected quantities can be seen as indicators for likely tendencies and directions, but certainly cannot claim external validity. Despite the overall very promising quantity and level of correlations, the experimental method may elicit the objection that complete spaces cannot be adequately represented by a single photograph. While this statement itself certainly holds true, it cannot serve as an argument against the internal validity of the study or the analytic approach. First, several studies (see Section 5.2) have convincingly demonstrated that affective appraisals based on color photographs do not

n partitions	symmetric	n features	hominess	privacy	enclosure	aesthetic quality	warmth	complexity	clarity	spaciousness	brightness	appreciation	simplicity	dynamics
1		1	1.832	**2.287**	1.897	1.468	1.899	1.442	1.321	1.739	**1.851**	**1.381**	**1.512**	1.190
2		2	1.890	2.312	1.994	**1.447**	**1.897**	**1.373**	1.333	1.799	1.923	1.410	1.527	**1.180**
2	✔	1	**1.831**	2.287	1.897	1.468	1.898	1.441	1.320	1.741	1.851	1.381	1.511	1.189
3		6	1.937	2.367	**1.736**	1.560	1.981	1.504	**1.318**	1.697	1.936	1.488	1.571	1.395
3	✔	4	1.937	2.316	1.738	1.575	1.989	1.521	1.342	**1.617**	1.972	1.472	1.513	1.363
4		8	2.290	2.878	1.988	1.741	2.209	1.556	1.544	1.985	2.072	1.710	1.727	1.209
4	✔	4	1.991	2.314	1.726	1.524	2.015	1.451	1.289	1.622	1.917	1.503	1.523	1.370
5		15	2.404	3.347	2.883	2.058	2.403	2.199	1.705	2.342	2.606	2.008	2.092	1.999
5	✔	9	2.270	2.615	2.140	1.736	2.428	1.809	1.592	1.859	2.371	1.763	1.825	1.646
6		18	2.902	4.955	2.707	3.014	2.914	2.299	1.938	3.125	3.327	2.603	2.848	2.067
6	✔	9	2.296	2.596	2.125	1.957	2.457	1.829	1.568	2.053	2.417	1.785	1.738	1.869

Table 7.2: Results from the comparison of the multivariate linear models. The table shows the standard deviation of the predicted values from the rated values in several model resolutions for all categories. The lowest deviations are indicated by bold letters.

strongly differ from ratings directly done on site. Additionally, since the scenes predominantly were not familiar to the participants, ratings could only be based on the information obtainable from the stimuli, and subjects had to extrapolate the remaining invisible parts from the given pictures. The analysis was based on the exactly same available data. Hence, also the analysis can claim internal validity, and even the measurands that turned out to render the highest correlations can be seen as promising candidates indicating general relations.

Frequency analysis. All in all, the analysis of the frequency based models suggests that they had predictive capabilities above chance level only for certain, predominantly denotative, experiential dimensions such as spaciousness, complexity, clarity, and enclosure. For other experiential qualities, the revealed correlation patterns (Figures 7.7) seem to reflect mainly random tendencies within the limited test sample and probably do not signify general trends. While this outcome is in accordance with the results of Oliva & Torralba (2001), tendencies as reported by Schira (2002) could not be corroborated. Direct correspondents to affective qualities did not become obvious, yet basic spatial properties could be coarsely detected by few pictorial frequency patterns. Apparently, these additional characteristic values did not allow further predictions of affective qualities. Since other studies strongly suggest a considerable influence of spatial properties (e.g., see Section 7.4), it can be assumed that this contrasting outcome was caused by some specific shortcomings of this study: First of all, a larger test sample would allow an increase of the frequency band resolution, which might lead to further and more accurate predictions. Likewise, a preselection of predictor frequencies for each experiential category by their single correlation might be useful. Finally, in these particular scenes effects of frequencies or of the spatial envelope might also have been masked or dominated by other factors like for example color and light. Yet generally, when available more direct spatial measurands (Sections 7.3 & 7.4) appear to be more promising than pictorial frequencies for describing relevant spatial properties.

Limitations. Due to the complete exploratory character of the study, there are several obvious limitations: First of all and already mentioned, the small number of sample scenes (only 15 subjectively selected scenes in each session) does not allow to claim any generality of the observed correlations. Additionally, several central design aspects of architecture such as spatial form and configuration were not covered by the analyzed factors, but varied between the scenes. So, due to the small scene set some of the reported correlations could also be artifacts caused by to a coincidental covariation. Therefore, any causal interpretation appears highly speculative. Finally, the selection process and the overall number of subjects did definitely not lead to samples representative for the two groups. Nevertheless, since many of the reported outcomes are well interpretable and fit to results of other studies, there seems to be a good chance that some actually indicate general tendencies. Methodologically, the simplest solution for most of the reported problems would be a repetition of the study based on a much larger number of rated scenes (at least a few hundred images) and also participants. While larger numbers of ratings per scene do probably not affect too much the rating means (cf. Russell, 1988), they would allow for more discriminatory differential analyses. Alternatively, more controlled stimuli and experimental conditions would have probably increased the external validity without requiring much larger sample sizes. So in sum, although these limitations allow questioning most individual findings of the experiment, they do not affect the main outcome that affective qualities can be well quantified and related to measurable properties of architecture.

7.2.8 Conclusion

All in all, the results of this preliminary study clearly supported the general approach of empirically studying the experience of architecture. In particular the results of the comparative analysis between appraisals and scene features promised novel insights into a topic that still is only marginally investigated. The data obtained from this analysis contained a lot of interesting details that virtually provoke further speculations, and indeed appear as suitable starting points for further more systematic experiments. Alternatively, since the detected factors were predominantly related to surface properties and lighting, additional exploratory studies could primarily concentrate on spatial properties of architecture that were at best indirectly represented by the image based measurands. Yet the importance of color and lighting for the affective experience, both factors which are normally easily influenceable, can be generally affirmed.

7.3 Study 2 - an architectural elements based approach

7.3.1 Overview

Also in this study (cf. Franz et al., 2003a) quantitative relations between the experience of architectural indoor spaces and their physical properties were explored. The analysis tested characteristic values capturing spatial properties obtained from architectural-elements based descriptions on their suitability as predictor variables for the affective qualities of rectangular rooms. In a virtual reality based perceptual experiment, 16 vacant indoor spaces were rated in eight principal experiential categories by 16 participants using the semantic differential scaling technique. The simulated scenes were automatically generated using a custom-made software tool that also provided the room descriptions.

The analysis revealed strong correlations between several scene features and the averaged affective appraisals: For example, preferences for large open spaces and for room proportions near to the golden section were found which are not directly perceivable. Altogether, a set of five widely independent factors (openness, two room proportions, room area, and balustrade height) turned out to be effective for statistically explaining the observed variance in the ratings. The architectural elements based scene descriptions appeared as a successful approach to provide comparability between standard rectangular indoor spaces and captured properties relevant for the experience.

7.3.2 Introduction

The findings of the precedent study (Section 7.2) strongly supported the initially assumed existence of systematic relations between physical properties and affective appraisals of architectural spaces. Due to the chosen image-based analysis, the revealed predictor variables mainly captured pictorial visual properties corresponding to surface characteristics and lighting. Architecture as a whole, however, is a product of many factors, and, even when preliminarily reduced to visual appearance, spatial, configurational, or functional properties likely affect emotional responses. In architectural theory, the importance of spatial properties has often been emphasized, since this concern most clearly distinguishes architecture from other disciplines. Hence, this study was designed as first approximation to a systematic analysis of influences of spatial factors.

7.3.3 Background

As discussed in Chapter 1, a central methodological prerequisite of a factor--analytic approach is quantitative comparability within both emotional responses and potentially emotion-affecting factors. The quantitative description of space and in particular spatial form is far from trivial. Generative and compositional description models (see Section 4.2.2) are either difficult to transform into few simple numerical dimensions, or their decomposition is often ambiguous.

Since the semantic meaning of architectural elements can normally be taken for granted and their actual composition is to a major degree determined by their function and constructive constraints, the approach chosen in this exploratory study was to completely abstract from compositional and topological properties and also from formal details, but to solely concentrate on directly comparable numbers and dimensions of basic architectural elements (see Section 4.2.1). It was initially motivated by the way spaces are described in colloquial language ("a narrow rectangular room with two small windows") and resembled the way construction works are defined in contract specifications. The component-based description model therefore solely contained on the quantities and basic dimensions of the rooms, windows, and doors. In principle, similar descriptions should be easily obtainable from any component-based CAAD system.

To a certain extent this kind of description also adopts the ecological perspective (see Section 4.4.2) of affordances (Gibson, 1979): Possible interactions with spaces widely depend on the availability of functional action units that correspond to structural components such as windows, doors, and floors. If a reasonable arrangement is taken for granted, their potential primarily depends on their availability, and secondary on their geometric dimensions, only to a lesser degree on relations.

7.3.4 Objectives

The primary goal of the empirical study was to exemplarily test quantitative interrelations between parameters from the component-based description model

Category	English low extreme	English high extreme	German low extreme	German high extreme
pleasure	unpleasant	pleasant	unangenehm	angenehm
interestingness	boring	interesting	langweilig	interessant
beauty	ugly	beautiful	hässlich	schön
normality	strange	normal	ungewöhnlich	normal
calm	arousing	calm	aufregend	ruhig
spaciousness	narrow	spacious	eng	weit
brightness	dark	bright	dunkel	hell
openness	enclosed	open	geschlossen	offen

Table 7.3: English translations of the rating categories used in the semantic differential. The experiment was conducted in German language.

and experiential qualities attributed to indoor spaces. Beyond that, the exploratory question was which combination of linearly independent factors would maximize the explained variance and thereby appear most suitable as predictors for experiential qualities. While, for example, the dimensions of a rectangular room can be defined by the three paramters length, width, and height, or equally unambiguously by its volume and two proportions, it is very likely that the proportion of overall explained variance differs. For this exploration, normative architectural knowledge for instance on proportions (see Section 6.3.1) appeared to be a suitable starting point. Additionally, it was particularly interesting to examine whether empirical results obtained in a virtual reality simulation would roughly correspond to classic rules as formulated by Palladio (1570) for instance, which to the author's knowledge had not yet been investigated psychophysically.

7.3.5 Method

In the perceptual experiment, 16 participants (8 females / 8 males) rated 16 virtual rooms in eight experiential categories. For each scene, the appraisal task was preceded by a 30 second exploration period. Subsequently, the experience of all interiors was evaluated using the semantic differential scaling technique (cf. Osgood et al., 1957; Heise, 1970). Each experiential category (Table 7.3) was represented by a pair of oppositional adjectives and could be rated on a seven step Likert scale. The electronic presentation allowed a complete randomization of the scene and rating sequence and also facilitated the recording of response times. The experimental data was complemented by a post-experiment questionnaire on the experimental task and experienced presence (cf. Section 5.3) during the simulation.

The stimulus set was generated using a custom made modeling utility (cf. Franz et al., 2003b, and Section 5.6) and consisted of 16 radiosity-rendered 360° panoramic images of vacant rectangular interiors (see Figure 7.8). The script based genera-

Figure 7.8: Screenshots of the 16 scenes used in the second study. (The dark spots on the floor were markers for a different experiment on spatial perception in VR, see Section 5.5.1).

tion process automatically provided the scene descriptions for the subsequent correlation analysis. To keep this test-of-concept study manageable, only a restricted set of design aspects was varied. The variance of the dimensions and positions of all structural components (e.g., walls, windows, doors, and ledges) corresponded to the normal ranges of real buildings. Other perceptual properties (surfaces, illumination, and surroundings) were constant over all scenes. The scenes were subjectively preselected from a larger randomly generated set of 48 interiors according to the criteria of maximal diversity and realism.

During the experiment the virtual observation point was at a fixed position for each room, slightly excentric from the center at a height of 1.60 m. The real eye height was at normal seating height (about 1.20 m). As display device, a spherical wide-angle projection system (Elumens VisionStation^{TM}, see Figure 5.6) offering a resolution of 1024x768 pixels was used. The simulated geometrical field of view (FOV) matched the physical FOV of about 130x90 degrees. The screen distance of the projection was approximately 75 cm. The technical setup did not allow for stereo projection, but the stimuli themselves offered several monocular depth and size cues: Absolute information was conveyed primarily by the virtual horizon height and inferable from angular declination. Also, the structural components and material textures provided additional cues, as their dimensions were in realistic ranges (cf . Section 5.5).

For the correlation analysis, the rating results of each scene were averaged by category over all subjects. As basic statistical parameter, the linear correlation coefficient *r* was chosen. When theoretically justified (e.g., for proportions), additionally non-linear trends were evaluated using quadratic regression fits. Significance levels were calculated using Pearson's product moment correlation coefficient, in the following result section a single asterisk (*) denotes an alpha-failure probability (i.e. the probability that the detected significant correlation is an artifact caused by random noise) below .05, two asterisks (**) a probability score below .01. The component-based scene description provided 12 primary characteristic values, which were the base for 13 further compound measurands. They are described in more detail in Appendix A.2.

7.3.6 Results

The variance in the ratings was fairly low, the mean of the standard deviation ranged from 1.13 (brightness) to 1.51 (calm) at an average of 1.36. The comparison to the equal distribution level of 2.16 indicated unimodal distributions and therefore meaningful intersubjective mean values. The response times, z-transformed per subject, were only slightly correlated with the extremity of judgments (correlation coefficient r_{mean}=-.18**), and thus not useful as an additional behavioral measure. According to the post-experiment questionnaire, participants felt moderately present (average rating 4.75 on a 7 step Likert scale) during the experiment, and were fairly content with the appropriateness of the medium (5.81/7) for the task and the general realism of the simulation (5.37/7).

As expected, denotative rating categories covaried with corresponding scene features (see Figure 7.9 for selected correlations). For example, spaciousness correlated with the actual room area (r=.84**), but the coefficient with overall window area was even higher (r=.92**). Perceived openness and brightness were highly correlated with the relative wall openness ratio (wall area / window area), which

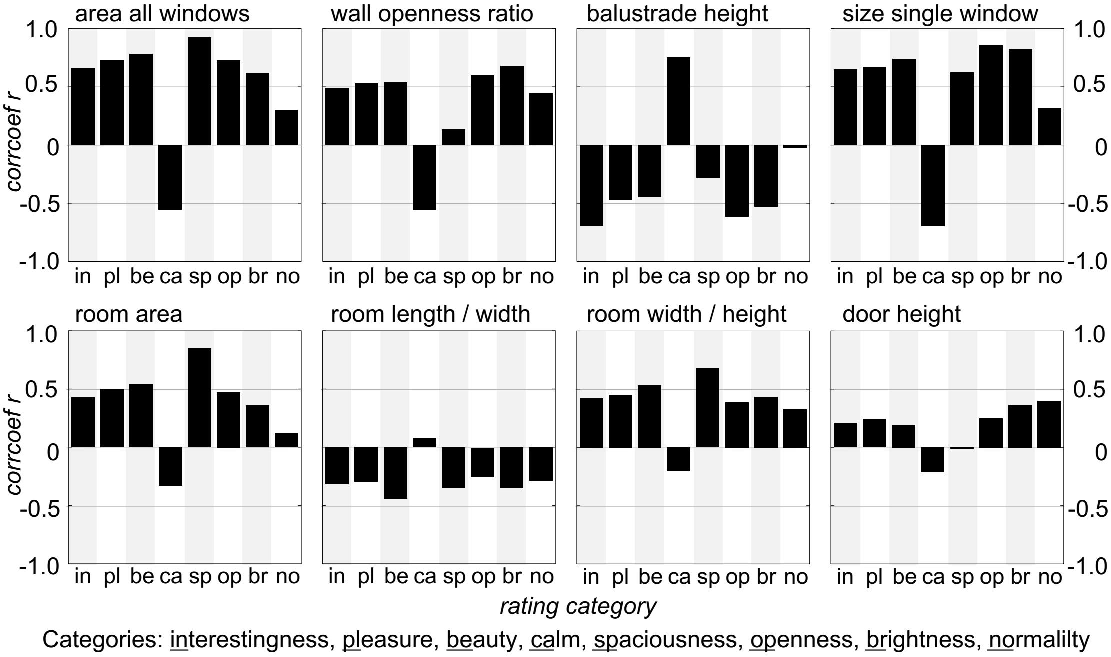


Figure 7.9: Linear correlations between rating categories and selected scene features.

is a direct correspondent to the physical brightness of the scenes. For rated openness, the comparison to the size of single windows rendered the highest correlation coefficient (r=.85**). The results of rated calm were widely oppositional to rated openness, it was negatively correlated with all factors influencing relations to the exterior as for instance balustrade height (r=-.75**) and window sizes (r=-.69**). In contrast to window parameters, door properties did not show significant effects in any rating category.

The three affective rating dimensions beauty, pleasingness, and interestingness appeared highly interrelated (correlation beauty - pleasingness r=.96**, beauty - interestingness r=.90**). Regarding their relations to scene features, the correlations with wall openness ratio were highest (e.g., beauty - wall openness r=.86**). Surprisingly, window proportions or numbers rendered no significant effect, apart from wall openness only balustrade height showed a considerable tendency (r=-.44, p=.08). With regard to room dimensions, from the tested combinations of linearly independent factors a set consisting of room area (r=.54*), the principal proportions width to height (r=.53*), and length to width (r=-.43, p=.09) yielded the strongest individual correlations with the affective rating dimensions. However, a quadratic regression for the correlations with room proportions revealed assumable dominant non-linear trends and showed maxima near to the golden section[3] (room length/width maximum at ratio 1.7, room width/height

[3]The golden section is defined as $\frac{major}{minor} = \frac{major+minor}{major}$. This corresponds to a ratio of $\frac{\sqrt{5}+1}{2}$ or approximately $\frac{1.618}{1}$.

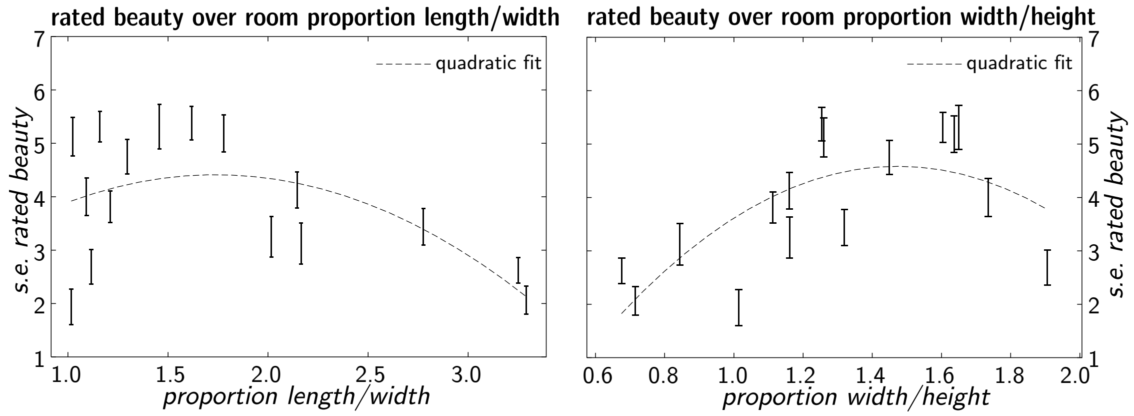


Figure 7.10: Nonlinear correlations between room proportions and rated beauty.

maximum at ratio 1.5, see Figure 7.10). In addition to these parallel main tendencies, also the differentiation in three affective categories appeared informative: interestingness was relatively more correlated with window properties, and beauty more with room proportions.

In contrast to our expectations, the ratings of normality and interestingness were not significantly interrelated. The only highly significant linear correlation of normality was detectable with physical openness (r=.65**). But square fitting revealed non-linear tendencies for several scene features (e.g., window dimensions and room proportions), indicating that average properties were seen as normal.

7.3.7 Discussion

The strong and widely linear relation between wall openness and affective ratings was not expected. It seems possible that this was partially caused by the particular attractiveness of the chosen urban background. The short period of exposure to each room and a the absence of a simulation of potentially incommoding environmental factors such as noise level and reduced privacy due to passers-by may have contributed to the entirely positive response to wall openness. Additionally, it has to be considered that in all rooms of the scene set two adjacent walls were always closed, and even in the the most open room window area did not exceed more than 20% of the total wall area, so wall openness was clearly not exaggerated and the design unintentionally adhered to design patterns as suggested by *prospect and refuge* and *defensible space* (cf. Section 6.3.3). The remarkably high correlation between rated spaciousness and window size may be interpreted as a compound effect of room size and openness, since room size obviously directly affects available wall area for openings, and an additional effect of the surround-

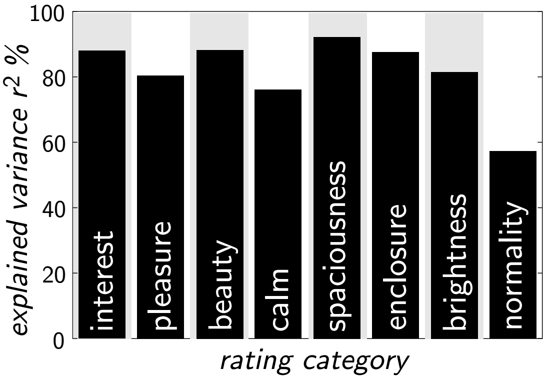


Figure 7.11: Explained variance by a multi-variate linear regression. Together the five linear factors openness ratio, room area, room width/length, room width/height, and balustrade height account for between 57% and 92% of the observed variance in the averaged ratings.

ing outdoor space is indicated by the correlation level with the physical openness ratio (r=.68**).

Overall, the results appear reasonable, since denotative ratings almost covary with corresponding scene features, and specific hypotheses based on normative rules were confirmed. The correlation between beauty ratings and room proportions is particularly remarkable, since these spatial properties were not directly perceivable, and could only be experienced by integrating several perspectives over time. These outcomes clearly support the validity of the simulation and show a substantial potential for investigating experiential qualities empirically. Many of the sometimes unexpectedly high correlations virtually provoke further speculations on causalities. As this is always problematic for correlations, it is preferable to consider them as descriptors or indicators that allow for probable inferences about experiential qualities. Altogether, from the tested combinations, a set of five almost independent factors (openness ratio, two room proportions, room area, and balustrade height, see Figure 7.11) appeared to be a very effective set of descriptors for the variance in the ratings of this scene set. While an entire linear separation of the factors is certainly mathematically possible, for example, by dividing openness by balustrade height, this set has the clear advantages of immediate interpretability and even practical applicability.

As regards the theoretical origins of the component-based description system, it shall be clearly stated that the analysis factors were not meant to constitute a model for mental representation or empirical scene and object recognition. Their primary objective was to effectively capture the differences in the scene set that are most correlated with attributed experience. Besides functional and spatial information, general perceptual properties such as brightness or pictorial frequencies (e.g., via the number of openings) are included indirectly in the measurands that would presumably emerge in other models. While the importance of the implemented ecological aspect should therefore not be overstressed, it is, on the other hand, a thought-provoking source for interpretations. For example, did the doors have no apparent effect because they had no function in the experiment? Or was room area so effective for pleasingness, in contrast to the normal connotation of coziness, because it just linearly increased the functional potential? Pointing in a similar direction, several participants reported that it would have changed their experience if they had been informed about the functional category of the rooms. Hence, as suggested by Kaminski (1976, pp. 255-257), a consideration of action and defined function could provide a basis for further refinements.

While for the purposes of this study configurational information was apparently negligible, the results of course do not implicate that relations between components are of minor effect. In fact, the tuning of the scene generator tool to produce just similarly "normal" configurations was a process of many successive refinements. Most architects would presumably consider this aspect of composition more delicate than reducing buildings to an array of roughly specified features. The scope of this test-of-concept study was deliberately limited to some variations of standard closed rectangular rooms. The chosen descriptors were particularly suited to capture the gist of these kind of spaces with a low complexity level and simple structural components with unambiguous composition. Of course, to be generally applicable, the description model has to be extended and adapted. While most individual results of the study appear generally convincing, due to the small and preselected scene set they certainly cannot claim general external validity. The method itself, however, has successfully shown its general potential. In sum, the revealed factors appear promising candidates for further more deepening investigations.

7.3.8 Conclusion

In this study, correlations between architecture described as an array of constructive elements and its experiential qualities were quantitatively explored. Virtual reality simulations proved to be a powerful means for fundamental architectural research that allows for optimized empirical methods. The results generally back the basic assumption that aspects of emotional experience can be empirically investigated and have determinable correspondents in the physical environment. Already a set consisting of five widely independent linear factors (openness, two room proportions, room area and balustrade height) from a component-based description allowed explaining a large proportion of the observed variance in the ratings. The high level of correlation is particularly remarkable for affective and aesthetic rating categories that cannot be trivially attributed to single scene features. The chosen representation model provided evidence both for the importance of perceptual features and for an affordance based view.

7.4 Study 3 - An isovist based approach

7.4.1 Overview

The previous experiment (Section 7.3) suggested that spatial properties such as room proportions and area are effective predictor variables for the affective qualities of rectangular architectural spaces (Franz et al., 2003a). Yet the detected factors were mainly only suitable for describing rectangular spaces, they obviously cannot be directly transfered to open-plan indoor spaces. Although the rectangular ground plan surely is the most widespread form of indoor space, a generically applicable analysis method would be clearly preferable.

In this section an approach is introduced that relates experiential qualities of arbitrarily shaped architectural spaces to their spatial form using isovists (Benedikt, 1979). In an exploratory psychological experiment, 33 characteristic values derived from the isovists were tested on their predictive power on experiential qualities by correlating them with averaged affective appraisals. Thirty-four fictive indoor scenes were rated by 2x8 participants using the semantic differential. The rooms were presented as radiosity-rendered 360° panorama images on a 130°x90° wide-angle virtual reality system. Particularly measurands capturing the qualities spaciousness, openness, complexity, and order turned out to be effective predictor variables. The findings are discussed in terms of evolutionary and information rate related theories of environmental preferences. Altogether, the study strongly suggests that isovist-based visibility graph analysis is a suitable means to generically describe emotion affecting spatial properties of architecture.

7.4.2 Introduction

In the discipline of architecture, the design of spatial configuration and form is traditionally regarded as its most prominent concern, in fact, spatial form has been called the primary dimension of architecture (e.g., Giedion, 1941, Joedicke, 1985, cf. Section 6.3.3). Also several theories from environmental psychology (e.g., Appleton, 1988, Kaplan, 1988a, Newman, 1996, cf. Section 6.4) relate human preferences and behavior to spatial properties of the environment.

However, current architectural textbooks (e.g., Krier, 1989; Ching, 1996) still recapitulate the normative rules of Alberti (1485) or Palladio (1570) from the renaissance age that are hardly empirically grounded and only cover circular and rectangular spaces. Regarding rectangular rooms, a previous experiment (cf. Section 7.3) indeed found high correlations between affective appraisals and their proportions, area, and openness ratio. Yet the question of how these rules and findings can be generalized to arbitrary spatial forms and open-plan indoor spaces remained completely unsolved. Apart from the general problem of quantifying experiences, an empirical investigation of emotional influences of spatial form is faced with two non-trivial main problems: Methodologically, spatial properties have to be systematically varied independent from other design factors, and, analytically, spatial form has to be described quantitatively in few generically applicable meaningful dimensions (cf. Chapter 4).

This section presents an empirical approach to the experience of architectural space based on a combination of virtual reality simulations (see Chapter 5) and a description of spatial properties using isovist and visibility graph analysis (see Section 4.2.4). The methodology was exemplarily tested in a psychological experiment comparing affective appraisals and isovist measurands of 34 virtual indoor scenes in order to determine the most promising predictor variables. For this purpose, existing theories and normative knowledge on affective qualities of space were translated into concrete hypotheses on correlations between isovist measurands and affective appraisals. In the following section the theories and methodological prerequisites underlying this approach are briefly resumed, the concrete hypotheses are presented in Section 7.4.4.

7.4.3 Background

As reviewed in Section 6.3.3, there are several theories that relate affective responses to spatial properties of an environment. Architectural theory (e.g., Joedicke, 1985) suggests that the most basic quality of architectural space, spatial density or *spaciousness*, is an important constituent of its affective experience. In addition to direct responses to spatial size, it has to be considered that this factor also widely determines the range of potential or preferred functions which may be an important basis for situation-dependent affective responses (cf. Section 6.4.1). So, in sum, moderately large and differentiated shapes offering diverse ways of utilization should have tendentially a higher valence than narrow or unstructured spaces.

Related to the basic spaciousness quality, the theories of “prospect and refuge” (Appleton, 1988) and “defensible space” (Newman, 1996) suggest preference patterns for certain configurations combining enclosure and *openness* (cf. Section 6.3.3). While this prospect and refuge theory was initially explicitly related to molar environments and not to single places, it has been often transferred on the analysis of rooms (e.g., Hildebrand, 1999).

A further group of theories relates affective responses to perception and information processing (see Section 6.4.3). Within the various concepts described in the literature, there are strong indications for at least two main dimensions, that may be provisionally identified and termed as *complexity* and *order*. While architectural theory tends to stress the aesthetic value of the latter (e.g., Weber, 1995), psychological experiments have rather concentrated on the effects of complexity. Complexity is seen as directly influencing the emotional dimension of arousal. Furthermore, mainly going back to Berlyne (1960, 1972), an indirect influence of arousal on pleasure has been assumed. So, taken together, the theories suggest that valence is tendentially highest in stimuli that combine high levels of complexity and order (cf. e.g., Nasar, 1988b).

Closely related to these static collative stimulus properties are concepts that relate to the *predictability* of an environment (see Section on page 110), suggesting increased arousal and potentially pleasure by environments promising new information when moving further. In addition to the effects on arousal and preferences for certain "optimal" levels of predictability, a very direct influence on dominance can be assumed. Actual predictions based on the factor predictability seem however difficult, since its influence strongly depends on non-physical factors such as previous exposure and familiarity.

7.4.4 Experimental questions

Objective. The briefly reviewed theories describe specific spatial qualities and their tendential mood-altering effects. Isovist and visibility graph analysis (Section 4.2.4) allows for a generic and quantitative description of spatial properties. In order to relate affective responses to measurable features of architectural spaces, an empirical study was designed that compared isovist derivatives to affective appraisals of architecture. The exploratory aim of the present experiment was a tentative identification of isovist parameters that appear to be most suitable for generally predicting experiential qualities. In order to keep the study small, a specific scenario was chosen that allowed to freely vary spatial properties independent from other properties. Several numerical factors derivable from visibility graph analysis appeared suitable to capture basic qualities that according to the reviewed theories (cf. previous section) likely affect emotional responses. The following paragraph gives an overview on thereof derived concrete hypotheses.

basic spatial quality	tendential emotional influence			isovist and visibility graph based descriptor variables	calculation method
	P	A	D		
spaciousness	/		∩	isovist area	neighborhood size
				free near (medium) space	n visible graph vertices at 2 (4) m distance
openness		/	\	isovist openness	$\text{length}_{\text{open edges}}$ / $\text{length}_{\text{closed edges}}$
				jaggedness	isovist perimeter^2/area
				revelation	(Σ area adjacent isovists - isovist area) / isovist area
complexity	∩	/		number of vertices	n isovist vertices, n segments
				vertex density	n vertices / area
				roundness	isovist area/perimeter^2
				jaggedness	isovist perimeter^2/area
				clustering coefficient	see Turner et al., 2001
order	/	\	\	symmetry	n symmetry axes
				redundancy	n_{segments} / $n_{\text{unique segments}}$ +1

Table 7.4: Summary of the hypothesized connections between emotional responses in the three dimensions pleasure (P), arousal (A), dominance (D) and selected isovist measurands based on four basic emotion-affecting spatial qualities. Slashes (/) indicate expected positive linear correlations, backslashes (\) negative linear correlations, inverted U's (∩) non-linear relations.

Hypotheses. The tentatively identified four basic emotion-affecting spatial qualities spaciousness, openness, complexity, and order were translated into concrete hypotheses on correlations between isovist measurands likely capturing aspects of these qualities and affective appraisals in different emotional dimensions. Table 7.4 gives an overview on these preliminary working hypotheses and on the calculation methods of the isovist measurands.

The basic *spaciousness* quality was expected to be approximated by measurands such as mere isovist area (also called neighborhood size) or the area of the the convex part of the isovist. Since convex partitioning is mathematically non-trivial and often ambiguous, it was decided to test for additional influences of distance by partitioning the visibility graph into multiple depth segments and calculating the proportion between actually and theoretically visible graph nodes at the given distances (measurands free near/medium space).

The second quality *openness*, motivated by prospect and refuge, defensible space, and predictability theories, was seen to relate to at least two different physical aspects, the number of vistas into adjacent rooms and the rate of physical enclosure. The former could be probably captured by measurands describing the convexity of isovists such as clustering coefficient and jaggedness, the latter simply by the openness ratio. Furthermore, a more behaviorally oriented measurand was designed called revelation coefficient that was calculated on the visibility graph as the relative difference between the area of the current isovist and its adjacent neighbors. Similar to the clustering coefficient, a high revelation coefficient indicates an area of low visual stability and potential information gain by moving further. Revelation might be especially relevant when actively navigating. In order to facilitate a distinction between openness-related measurands and spaciousness, all these measurands were basically scale invariant.

The third group of factors summarized in the concept of *complexity* was expected to denote either the absolute amount of information or features, or the relative information density. Reasonable approximations for measuring complexity could therefore be the number of vertices or segments making up the current isovist, vertex density, and again clustering coefficient, or the isovist jaggedness. Similar measurands have been successfully used by Berlyne (1972) to describe pure polygons and by Stamps (2000, pp. 39-43) for building silhouettes. Although derived from a quite different theoretical background, an overlap with measurands capturing openness became apparent.

Finally, as regards properties contributing to visual *order*, some conceptual relations to factors influencing clarity were assumed, implicating correlations to isovist openness or more global visibility graph properties such as first order isovist divided by second order isovist. Besides that, normative architectural theory (Ching, 1996) mainly suggested that order might be approximated by redundancy patterns within the isovists, such as symmetries or absolute and relative number of unique polygon sections. Since none of the existing mainly topologically-oriented measurands from the space syntax literature related to such kind of factors, several mathematical combinations of the basic measurands were generated. For an empirical validation of their hypothesized relation to visual order, eight participants sorted printed cards showing 16 isovist polygon contours (cf. Figure 7.12) according to the criterion of regularity. Afterwards, they were asked to mark a potential aesthetic tendency within their sequence if apparent. The subsequent analysis showed a large consistency within the rankings. Two structural main factors became apparent: The average ranking could be described almost perfectly (correlation coefficient r=0.94, p<.001) by the formula:

$$polygon\ regularity = -\frac{n_{unique\ polygon\ sections}}{n_{symmetry\ axes} + 1}$$

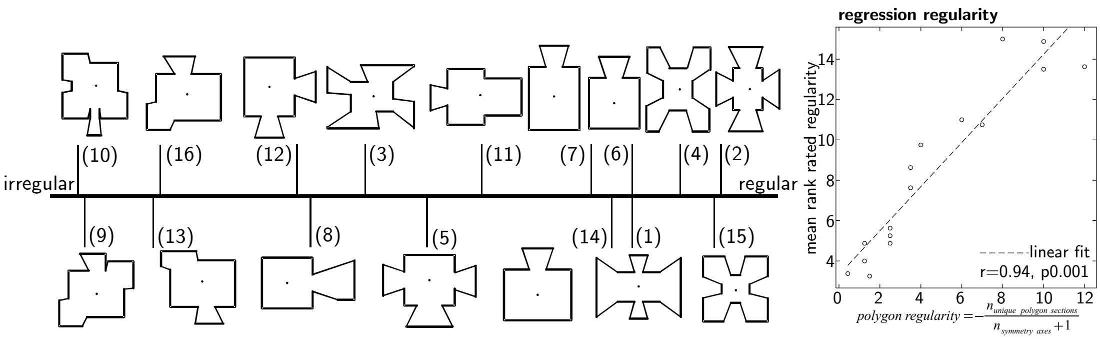


Figure 7.12: Averaged result of the regularity ranking of the isovist polygons and scatter plot mean ranked regularity over regularity computed by the regression formula.

The marked aesthetic tendency of the isovist outlines was uniformly parallel to the order ranking. Methodologically, the automatic detection of the underlying properties appeared to be difficult, partially due to issues of computational accuracy, partially due to the unclear relevance of imperfections, suggesting the notion of partial symmetries. Therefore, for the following exploratory empirical study the regularity factors were evaluated manually for each scene only at the observation point.

7.4.5 Method

Procedure. In the empirical experiment two groups of eight subjects rated the experiential qualities of altogether 34 spatial situations in a fictive art gallery. The empirical study consisted of a pilot stage comprising 18 empty rooms and a second main stage using a refined set of 16 stimuli. The data was collected using semantic differential scaling in seven primary experiential categories. The rating categories were represented by pairs of oppositional adjectives (cf. Table 7.5) and were selected in order to comprise major dimensions of affective experience (pleasure, beauty, and interestingness) as well as denotative and collative properties related to the assumed basic spatial qualities (experienced spaciousness, openness, clarity, and complexity). The openness rating category was only used in the first stage. Subjects could differentiate their appraisals using a seven step Likert scale. Before the ratings, subjects had thirty seconds to freely explore the scenes. They were explicitly advised to survey the complete room. Afterwards, the rating dimensions were presented separately at the lower screen border. Subjects were instructed to respond quickly and to base their judgments on their first impression, yet no explicit time constraint was given. The presentation order of the scenes and the ratings was completely randomized for each participant. To avoid potential biases on the affective ratings caused by the collative rating di-

Category	English low extreme	English high extreme	German low extreme	German high extreme
interestingness	boring	interesting	langweilig	interessant
pleasingness	unpleasant	pleasant	unangenehm	angenehm
beauty	ugly	beautiful	hässlich	schön
spaciousness	narrow	spacious	eng	weit
enclosure	open	enclosed	offen	geschlossen
complexity	simple	complex	einfach	komplex
clarity	unclear	clear	unübersichtlich	übersichtlich

Table 7.5: English translations of the rating categories used in the semantic differential. Study 3 was conducted in German language.

mensions suggesting evaluation criteria, in the second stage the two rating category groups were separated in two subsequent blocks. A complete experimental session took about 45 minutes. The 16 subjects voluntarily participated in the experiment; they were paid eight Euro per hour. They were mostly university students at an age of 20-25 years.

Setup and stimuli. The study was conducted using a virtual reality simulation setup. The stimuli were presented as 360° panorama images on a spherical wide-angle projection system (Elumens VisionStation^{TM}, see Figure 5.6). The simulated visual field matched the physical field of view of 130°x90°, the screen width was 151 cm, participants experienced the virtual environments from an egocentric perspective at a screen distance of about 90 cm. The virtual observation points were fixed, but subjects could choose their gaze direction freely. They interacted with the simulation using a trackball for navigation and the number keys of a standard keyboard for the ratings.

The two scene sets mainly differed with respect to the variance range of visible room area, in the second scene set this parameter was much more restricted (see Figure 7.15). Additionally, the number of vistas and alcoves were more systematically varied, and the walls were draped with unobtrusive paintings (46 portraits from Picasso's blue and pink period, cf. Figure 7.15) to tentatively increase curiosity and thereby the effects of occlusions and vistas. Other surface properties and also the illumination level were kept constant over the scene sets. The geometry models were created in AutoCAD, the physics-based radiosity scene illumination was generated using the free POV-Ray rendering package (`http://www.povray.org`).

Analysis. For the spatial analysis in this study, the techniques of isovist and visibility graph analysis were combined: the 34 virtual indoor scenes were analyzed by calculating isovist measurands and visibility graphs on a 50 cm grid covering the whole environments. For doing this analysis, a special isovist analysis

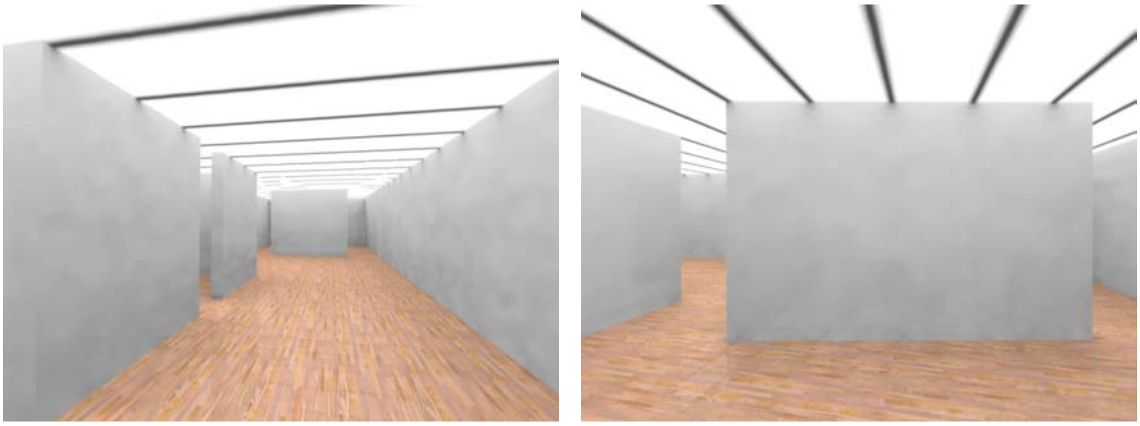


Figure 7.13: Example screenshots from the first stage.

Figure 7.14: Example screenshots from the second stage. The walls were additionally draped with paintings to tentatively increase the effects of occlusions and vistas.

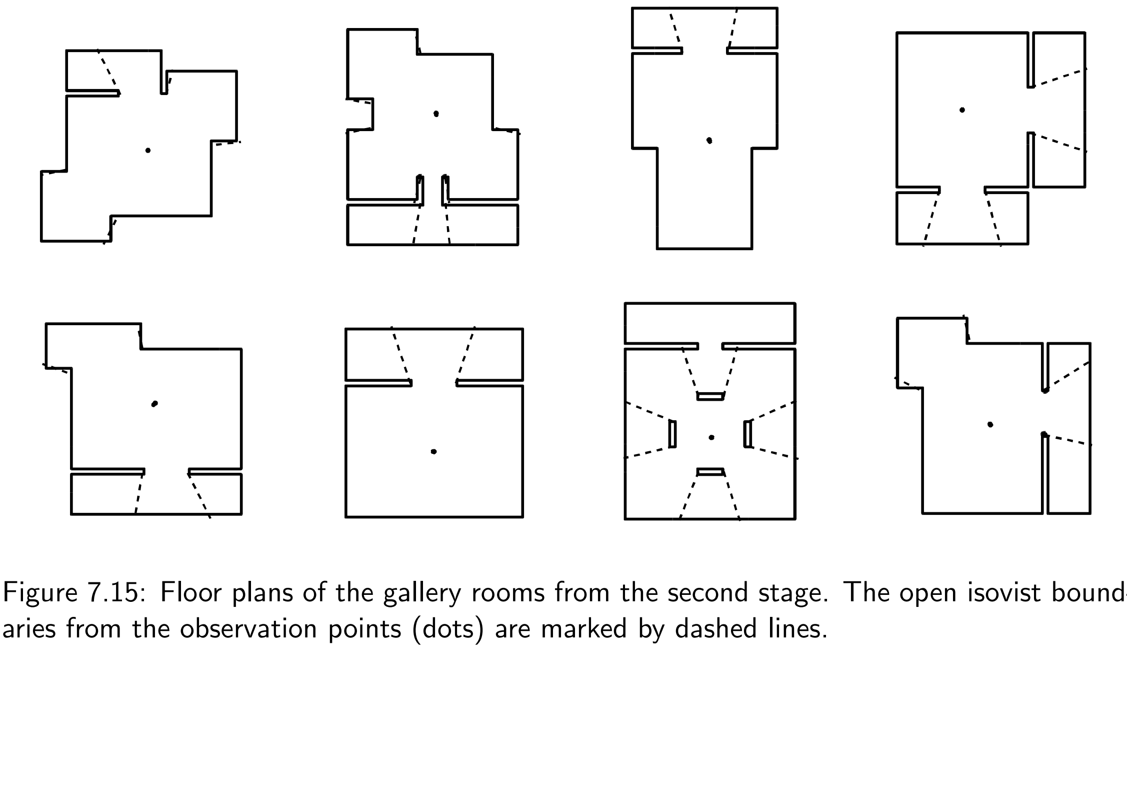


Figure 7.15: Floor plans of the gallery rooms from the second stage. The open isovist boundaries from the observation points (dots) are marked by dashed lines.

tool was developed, the tool is free software and available at `http://www.kyb.mpg.de/~gf/anavis`. Apart from visibility graph measurands from the literature (mainly Turner et al., 2001) and several descriptors of the isovist polygon from empirical aesthetics (e.g., roundness, cf. Berlyne, 1972; Stamps, 2000), further novel measurands were designed to particularly capture spatial properties fitting to the initially formulated hypotheses (cf. Table 7.4 and Appendix A.3).

In the statistical analysis, averaged ratings from eight participants in each stage were compared with altogether 33 characteristic values describing the isovists from the particular observation points in the scenes (See Figure 7.15). The rating data was treated as even interval scaled. Linear correlation coefficients r were calculated using Pearson's product moment correlation, p-values indicate the probability of the non-directional null hypothesis. P-values below .05 were treated as significant correlations. Confidence intervals (95% CI) describing the likely range of the general population correlation coefficients were obtained from a Fisher r-to-z transformation. Nonlinear relations were evaluated qualitatively via fitting square regression functions, but no significant non-linear interrelations became apparent. The statistical analysis was performed using the mathematical software GNU Octave (`http://www.octave.org`) and SPSS (`http://www.spss.com/spss`).

7.4.6 Results

Pilot stage. The first experimental stage revealed isovist area as dominant factor (see Figure 7.16 a). It was highly correlated with all rating categories (explained proportion of variance r^2 from .67 to .82, $p<.01$) except for clarity which showed a high negative correlation with vertex density ($r=-.81$, $p<.001$, 95% CI -.93 to -.52, Figure 7.16 b). Consequently, all other rating categories were highly interrelated ($r^2>.47$, $p<.01$). Most prominently, rated spaciousness and enclosure turned out to be almost identical ($r^2=.96$, $p<.001$). So, for the next stage the enclosure rating category was dropped and the variance of isovist area was restricted.

Second stage. In the second scene set, rated spaciousness ($r=.83$, $p<.001$, 95% CI .57 to .94) and beauty ($r=.73$, $p<.01$, 95% CI .36 to .90) were still strongly correlated with isovist area, but the introduced constraint allowed further observations (cf. Figure 7.17): A multivariate linear regression analysis found pleasingness to be best explained by the additional factor enclosure ratio ($R^2=.69$, $p<.01$), and interestingness by the number and density of vertices, and the roundness and openness of isovists ($R^2=.73$, $p<.01$). Also, complexity was correlated highest with the number of vertices ($r=.81$, $p<.001$, 95% CI .52 to .93), while rated clarity showed a strong correlation with isovist roundness ($r=.93$, $p<.001$, 95% CI .80 to

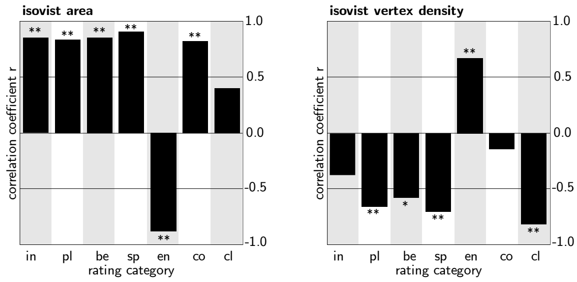


Figure 7.16: Results of the first stage, showing isovist area as dominant main factor. The rating categories were *in*terestingness, *pl*easingness, *be*auty, *sp*aciousness, rate of *en*closure, *co*mplexity, and *cl*arity.

.97). In contrast to the first session (r=-0.05), both factors were now also considerably interrelated (r=-.82, p<.001, 95% CI -.93 to -.54). Regarding measurands subjectively related to order, in particular the number of symmetries turned out to explain additional variance (e.g., correlation pleasingness r=-.75, p<.001, 95% CI -.90 to -.40). Unfortunately, this effect could not be clearly discerned from the free near space due to a probably coincidental covariation (r=0.90, p<.001, 95% CI .73 to .96). Additionally, redundancy was significantly correlated with rating results (e.g., pleasingness r=.66, p<.01, 95% CI .24 to .87, clarity r=.63, p<.01, 95% CI .19 to .85). Interestingly, the beauty ratings of the virtual reality scenes were opposite to the beauty ranking of the corresponding isovist polygons: Regular polygons were consistently estimated to be tendentially more pleasing, whereas the polygon regularity ranking was negatively correlated with rated room beauty (r=-.49, p=.05). Altogether, the explained variance of the averaged ratings varied between .69 (pleasingness) and .94 (clarity), the variables rendering the highest correlations were isovist area, openness, roundness, number of vertices, vertex density, and number of symmetries.

7.4.7 Discussion

The dominance of just one factor as found in the pilot stage was not expected. This outcome as well as the more differentiated findings in the second stage may be explained either by differences in the variance range of the different factors or by intercorrelations between the physical properties. Since the relative variance of isovist area did not exceed other measurands, the latter explanation is supported. Although most measurands were mathematically scale-independent, architectural forms are not. They are substantially determined by the absolute human scale, implicating intercorrelations. Since spatial features below a certain extent would be behaviorally irrelevant for humans, one can expect them to be found depending on the room size. Yet apart from that, visual spaciousness can

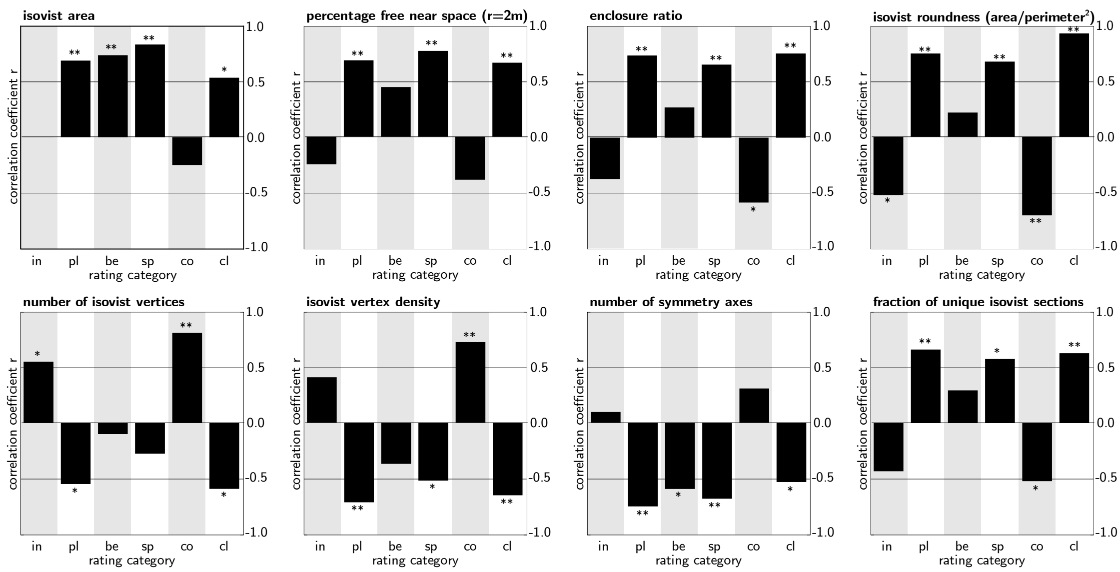


Figure 7.17: Most prominent results of the second stage. Correlations between selected scene features and ratings. The rating categories were *in*terestingness, *pl*easingness, *be*auty, *sp*aciousness, *co*mplexity, and *cl*arity.

be indeed assumed as a major factor for the experience of spaces because also the second stage found high correlations between ratings and isovist area and the result is in accordance with the theories.

Generally, the diverse results of the second stage turned out to be well interpretable and fitted the initial hypotheses remarkably well. The demonstrated medium or even large effect sizes as compared to the typical level of social science studies (cf. Cohen, 1988) approved the assumed descriptive power of the isovist measurands as well as the relevance of the four basic spatial qualities for the affective experience. Furthermore, the high correlations with denotative and collative rating categories approved the assumed descriptive power of the isovist measurands. The observed correlations corresponded qualitatively to the main effects reported in Section 7.3, the best isovist-based predictor variables appear to be suitable generalizations of the regressor factors of the previous study. Regarding the theories underlying the initial hypotheses, the correlation between pleasingness and enclosure is particularly in accordance with Newman's (1996) concept of defensible space. Also evidence for preferences for environments offering prospect and refuge (Appleton, 1988) was indirectly found, since both a jagged spatial profile and large visual areas were tendentially rated to be more pleasing. A more direct test comparing the relation between the convex core space and concave bulges of the isovist was not done, because a necessary optimal convex subdivision turned out to be ambiguous needing further criteria that could not be objectively determined.

The three regression factors for interestingness (which widely corresponds to the emotional dimension arousal) isovist roundness, vertex number and density were in accordance with classical information rate theories (e.g., Berlyne, 1972; Mehrabian & Russell, 1974). The even higher correlations for rated complexity clearly support the conceptual connection. It is worthwhile mentioning that similar measurands that allowed predictions on the experience of facades and house silhouettes (cf. Stamps, 2000) apparently generalize on the form of indoor space. Similar to Stamps (2002), no evidence for an inverted U-curve relation between pleasure and arousal was found. However, since the range segment of tested complexity was arbitrarily chosen and only one visual factor was varied, the results are not really contradicting the theories of Berlyne (1960, 1972).

The opposite aesthetic tendency between the ratings of the rooms and viewshed polygon outlines was puzzling at first glance. Given that order ratings of the virtual scenes correspond to the rankings of the polygons, one could tentatively explain the result by different effects of visual order on different scales: If a simple regular form completely dominates the visual experience, this might rather lead to understimulation and boredom that assumably outmatches positive effects of increased perceptual coherence. This interpretation can also be supported by the finding that negative correlations of symmetry and redundancy were stronger with pleasingness than with beauty. Pleasingness can be assumed to be more directly affective, while beauty may bear a bonus for formal qualities, which should correspond to order. Furthermore, effects of the particular observation points can be hypothesized. To offer a good overview, the selected virtual observation points were placed close to the centers of largest sub-spaces. These particular places were further accentuated by the symmetries, potentially inducing in the subjects an unpleasant feeling of being exposed. One might decide between the two interpretations by complementing the study with additional experimental conditions that either use different observation points or allow ego-motion. From a methodological point of view, this finding clearly demonstrates the dependency of affective qualities on the scale of the stimuli and backs the full-scale simulation approach of virtual reality.

Finally, the question of real world transferability and generalization of the results shall be discussed. With regard to that, several limitations of the study have to be considered. First, the general design of the experiment was exploratory, therefore the selection of subjects and the sample size were not guided by demographic criteria. However, the findings of Schroeder (1984, after Russell, 1988) and Stamps (2000, pp. 114-134) suggest that already such small sample sizes provide a good approximation to actual population responses. Second and more serious are potential limitations due to the particular context "experiment" and the chosen scenario. Consciously evaluating spatial situations during a laboratory experiment in a short exposure time is quite different from casually experiencing real spaces in normal life. Furthermore, the particular scenario art gallery was deliberately chosen to allow a wide variance of spatial situations. However, the transferability on other functional contexts cannot be taken for granted. Also interactions with other factors such as color, lighting, furniture, or presence of other people are possible that may substantially affect the observed relationships. In summary, it is expected that mean affective appraisals of corresponding real gallery spaces would be very similar, however, clear predications on the universality and the actual quantitative relations cannot be done. Nevertheless, the revealed predictor variables are well interpretable and appear reasonable, hence they are promising candidates for indicating generally relevant relations.

7.4.8 Conclusions

The experiment empirically demonstrated significant correlations between spatial properties and affective appraisals of spaces. Isovists and their derivatives proved to be a suitable means for describing important perceptual properties of spaces generically: Already a few basic measurands explained a large proportion of the observed variance in the ratings. The revealed main factors fit theoretical assumptions very well. The further empirical exploration of regularity related factors convincingly showed that also perceived visual order can be related to plausible measurable properties that are relevant factors for the experience of architectural spaces as well. While, due to the small number of scenes, the measured numerical values do not claim quantitative validity, it is likely that the observed main effects indicate generally relevant factors.

Future research should be primarily directed toward a broadening of the data basis. This would allow for a parallel consideration of several design aspects and thereby substantially increase the real world transferability of findings. Finally, the methods of isovist and visibility graph analysis bear a broad potential for further refinements: For example, a really generic method must be somehow extended to the third dimension and integrate more than one observation point, also differences between behavioral and visual space (e.g., due to windows or curtain walls) need to be considered. Nevertheless, the substantial potential of the methodology can be generally confirmed.

7.5 Study 4 - an integrative approach

7.5.1 Introduction

Everyday experience as well as normative architectural knowledge suggest that a multitude of environmental features and architectural properties contribute to the overall experience of spaces, for example spatial form, lighting and surface properties, furnishing, detail definition, sound ambience, and the surrounding context, to mention just a few. Several studies have empirically demonstrated systematic influences of single factors individually (see Chapter 6 and previous Sections 7.2, 7.3, and 7.4). However, in real world buildings many factors are parallelly present and lead to coherent and distinct experiences. Analogously, perception and experience are holistic parallel processes normally combining several sources of information in consistent percepts. Despite this basic awareness, little is known about the interaction and integration of different factors that actually takes place when humans experience architectural environments. However, for actually predicting affective qualities of real world spaces, a basic knowledge on the interplay of factors is indispensable. Hence, this question was exemplarily addressed in this experiment.

Each of the previous exploratory studies concentrated on one kind of factors (pictorial, architectural elements, spatial) that were systematically varied while other properties were kept constant. Correspondingly, only one particular description system of environmental or architectural properties was used in each study. So, in addition to an exploration of the interaction of factors, this final study also offered the opportunity to compare the previously developed analysis methods directly, promising first insights in correspondences of factors from different description systems and in relative strong and weak points of the approaches.

An investigation of the interaction of various factors can be done best by varying them parallelly over a set of stimuli. This implicates a multiplication of the necessary trials and scenes to get reliable results. Therefore, in contrast to the previous experiments that varied only few factors, this study had to be designed broader with respect to the number of scenes and participants. To keep the study still manageable, the variations were restricted to solely two yet broad classes of factors (architectural elements and surface colors), and the data raising was done in an experiment using the internet.

7.5.2 Background

While there are several theories on the influence of single factors on affective responses (see Chapter 6), to the author's knowledge, theories or models on the interaction of factors influencing experience or affective qualities do not exist yet. However, some outcomes of single factors studies allow at least specific hypotheses: In most precedent studies significant correlations between rated affective qualities and multiple linearly independent scene features became apparent. In other words, these statistical observations could be interpreted as superimposed independent effects that apparently did not influence each other. Therefore, one plausible hypothetical model could be termed superimposition without interaction. This hypothetic models gains further support by an analysis of the distribution of individual affective appraisals (cf. Section 8.4) that usually approximate a normal distribution. Since the general linear model (GLM) of statistics explains the often recurring Gaussian distribution of real world phenomena basically as sum of a multitude of independent underlying factors, it therefore appears justifiable to transfer this mechanism as reasonable assumption explaining the distribution affective responses. On the other hand, some empirical results also point in a different direction. For example, the two experimental stages of Study 3 (see Section 7.4) rendered completely different overall pictures: While the results of the second stage fit well to the outlined superimposition model, all ratings of the first stage were apparently entirely dominated by just one environmental factor (visible area). This measurand explained alone more than the half of the variance, and no further factor contributed significantly to the overall explained variance of the ratings. This result rather corresponds to a "winner-takes-it-all" model, meaning that the most extreme factor mainly determined the overall response.

If one wants to integrate the reported findings into a single overall model, they could be tentatively interpreted as follows: In cases where all factors are in "normal" ranges, different factors contribute together in a linearly independent manner. If a feature is however extreme, it rather dominates the final result alone. This hypothetical model gains some further support by two observations: First, in colloquial language architectural spaces are characterized by some introspective scales as well as by using just single outstanding features (see Section 2.4). The second argument arises from the notion that central aspects of emotion can be essentially understood as immediate and highly integrated evaluative responses to a stimulus with respect to the current context (cf. Section 6.2). Correspondingly, affective appraisals in the context of diversive exploratory behavior can be rationalized as evaluations of the general potential of a place or environment. Since such an assessment should ideally consider implicitly many possible utilizations, and different physical factors may contribute to the usefulness differently in dependence on the criteria, an integrated sum of independent and possibly weighted appraisal factors should optimally represent the statistical average potential. In extreme cases, however, the consideration of just one dominating factor appears to be more reasonable than a mediation by further secondary aspects.

7.5.3 Objectives

The study aimed at an exemplary investigation of the interaction of multiple factors from different design aspects contributing to the experience of architectural space. More specifically, the hypothesis was tested that in normal cases overall affective responses can be seen as a superimposition of independent individual factors. For this exploratory purpose, the interaction of just two clearly independent architectural design aspects appeared to be a good starting point. The interaction of spatial properties and surface properties was selected, because architectural theory and previous studies provided already basis knowledge on the expected influences of the individual factors (See Sections 6.3.2 and 6.3.3). Additionally, the design aspects could be independently varied and easily combined.

Furthermore, the study offered the opportunity to compare the different analysis methods that were developed during the previous studies directly. Here specific attention was turned to correspondences of factors from different description systems, and their relative proportions of explained variance.

7.5.4 Method

Experimental design. Since it was hypothesized that the combination of two independent types of stimulus properties would basically lead to some sort of a superimposition, the overall number of effective factors was expected to be a sum of the individual ones. Hence, to render this potential multi-dimensional result clearly, the total number of stimuli had to be much higher than in the single factor studies. So, instead of 16 scenes, altogether 64 scenes seemed to be appropriate for presumably six factors. Such a large number of scenes could not be assessed by one person, because then an experimental session would had taken around two hours, inevitably leading to strong global order effects due to fatigue. Consequently, the complete set had to be distributed over several participants. Since absolute rating scores tend to be adjusted to the sample (Russell, 1988), no fixed subsamples were used, but individual random subsamples were presented. The controlled randomization algorithm made sure that all scenes were rated by a similar number of participants.

Procedure. Due to the large number of stimuli and necessary participants, the study was designed as an internet-based experiment similar to Study 1 (see Section 7.2). Before the experiment, participants were briefed in detail on the general purpose of the experiment and its operation via an introductory website. Afterwards, personal and technical data were collected on a voluntary basis using a web-based questionnaire. Then the participants proceeded to the actual experiment. On the left-hand screen side, eight seven-step semantic differential scales were displayed in random order that represented major dimensions of affective experience by pairs of oppositional adjectives (see Table 7.6). The used scales were based on the previous experiments, additionally two rating categories were added presumably capturing the dominance dimension of affect (unobtrusive - obtrusive, light - oppressive). The actual stimuli were presented on the central and right half of the screen at a resolution of 640x480 pixels. Instead of using still images, the stimuli were displayed as panorama images using a small Java applet (PTViewer by Helmut Dersch, see `http://webuser.fh-furtwangen.de/~dersch/`). Subjects could freely choose their gaze direct by dragging the mouse in the display window. In the pre-experiment briefing, they were explicitly advised to train the navigation there and to examine the complete room carefully before rating the scenes. Regarding the ratings, subjects were instructed to respond quickly and to adhere to their first impression in case of indecisiveness. Only after completing the rating in all eight categories, subjects could proceed to the next scene by pressing a button.

Each participant was allowed to rate a subsample of 23 scenes, yet they could to terminate the experiment at any time by pressing a button on the web interface. A complete experimental session took around 45 minutes.

Stimuli. The experiment was based on 64 virtual indoor scenes (see Figures 7.18 and 7.19) that widely resembled the stimuli used in the experiments described in Sections 5.5.1, 5.5.2, and 7.3. Again the study was based on an automatically generated balanced set of vacant rectangular rooms (generated by the SceneGen tool, see Section 5.6) whose architectural elements were varied in similar ranges as occurring in real buildings. In contrast to previous experiments, also the wall color was systematically varied by dividing the HSV color space in 16 equal hue bands and using 4 different saturation and value (i.e. brightness) levels (cf. Figures 7.18 and 7.19). The indoor scenes were surrounded by a constant urban background (image texture).

Figure 7.18: Screenshots of the first half of the scenes used in Study 4.

Figure 7.19: Screenshots of the second half of the scenes used in Study 4.

Dimension	Category	English low extreme	English high extreme	German low extreme	German high extreme
valence	pleasingness	unpleasant	pleasant	unangenehm	angenehm
	beauty	ugly	beautiful	hässlich	schön
arousal	excitement	calming	exciting	beruhigend	aufregend
	interestingness	boring	interesting	langweilig	interessant
dominance	obtrusiveness	inobtrusive	obtrusive	zurückhaltend	aufdringlich
	gravity	light	oppressive	leicht	drückend
spatiality	spaciousness	narrow	spacious	eng	weit
	enclosure	open	enclosed	offen	geschlossen

Table 7.6: Semantic differential rating categories used in the experiment.

Analysis. From the stimulus scenes characteristic values were derived using the three different description systems of the previous experiments. The primary analysis was based on the architectural-elements based scene descriptions that were also used to generate the stimuli (cf. Section 7.3). In addition to characteristic values describing the numbers and dimensions of all architectural elements (floor, wall, windows, and doors), the systematically varied wall color was recorded in three color spaces (RGB, HSV, and L$\alpha\beta$). In order to detect correlations with individual color hues, HSV hue values were linearized between complementary colors and evaluated in steps of 1°. Altogether, in the architectural elements based analysis 40 descriptor variables and 179 wall color hue scales were entered (cf. Appendix A.4).

An additional comparative analysis was done using basic global pictorial characteristic values as described in Section 7.2.6 on page 121. For this step the spherical panorama images were cropped to the central three quarters and rescaled to a size of 682x256 pixels. Further spatial measurands were obtained using isovist analysis as described in Section 7.4.5 on page 141. In this analysis the room windows were conceived as completely transparent, and the vistas in the adjacent urban space were included in the visual profiles. The comparative analysis was based on 24 global pictorial descriptor variables, 179 further global color hue scales, and 29 isovist measurands.

The statistical analysis was primarily based on multivariate linear regressions. That is to say, the characteristic values derived from the scenes were analyzed for sets of significant regressor variables for the ratings. The algorithm was based on a forward strategy, variables were added to the regressor set as long as significant ($p<0.05$) partial correlations were found. Additionally, nonlinear relations

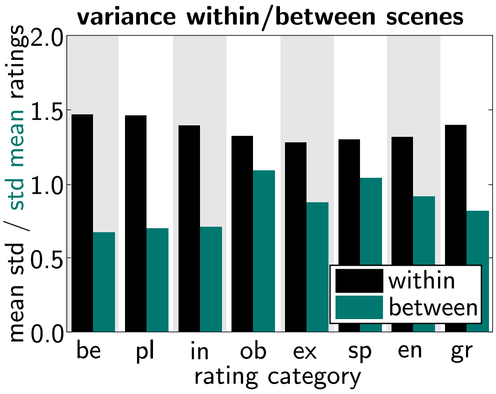


Figure 7.20: Comparison of the variance within and between scenes for each rating category. The rating categories were beauty (be), pleasingness (pl), interestingness (in), obtrusiveness (ob), excitement (ex), spaciousness (sp), enclosure (en), and gravity (gr).

were evaluated qualitatively via fitting square regression functions. Yet since no significant non-linear interrelations became apparent, the following section concentrates on the results from the linear analysis.

7.5.5 Results

General. Altogether, 91 participants contributed to the ratings, 761 complete ratings were recorded, at average each participant rated 8.3 scenes. Each scene was assessed at least eight times, on average 11.8 independent ratings were pooled together to get the characteristic values for each scene and rating category. The variance within the ratings for each scene was fairly constant over all rating categories, the standard deviation was around 1.4 (in comparison to 2.16 that would correspond to an equal distribution on a 7 step Likert scale), indicating unimodal rating distributions and therefore meaningful mean values (see Figure 7.20). The level of variance between scenes was tendentially lower and differed considerably between the rating categories, it ranged from 0.67 (beauty) to 1.09 (obtrusiveness).

Architectural elements based analysis. Generally, the factors entered in the multivariate linear regression were able to explain between 46% (interestingness) and 87% (spaciousness) variance of the averaged ratings (see Table 7.7). For all rating categories except of interestingness, factors describing the room geometry as well as factors describing the wall color significantly contributed to the overall result. Often recurring regressors were L$\alpha\beta$ luminance and the saturation of the L$\alpha\beta$ α dimension (i.e. the intensity of red/green hues). From the spatial descriptors, mainly openness related descriptors and room proportions contributed significantly to the explained variance.

Rating category	Explained variance R^2	Regressor variables
pleasingness	0.54	saturation L$\alpha\beta$ α, openness
beauty	0.55	saturation L$\alpha\beta$ α, openness, proportion RGB red, room proportion w/h, area single window
excitement	0.76	saturation L$\alpha\beta$ α, RGB green, room proportion l/w
interestingness	0.46	HSV saturation, HSV hue 128
obtrusiveness	0.86	proportion RGB green, HSV saturation, HSV hue 117, room proportion w/h, number of windows, HSV value
gravity	0.74	area all windows, L$\alpha\beta$ L, saturation L$\alpha\beta$ α, area single window
spaciousness	0.87	minimum wall distance, area all windows, L$\alpha\beta$ L, balustrade height, window height
enclosure	0.73	area all windows, L$\alpha\beta$ L, balustrade height

Table 7.7: Overview results of architectural elements based multivariate linear regression analysis, abort criterion p_{max}=0.05. For an explanation of the regressor variables refer to Appendix A.2.

An additional detailed analysis of correlations to HSV color hues revealed significant correlations between on the one hand rated excitement (correlation coefficient r=.32, p<.01), interestingness (r=.25, p=.05), obtrusiveness (r=.27, p=.03), and gravity (r=.27, p=.03), and on the other hand color hue scales all going from green to magenta hues (cf. Figure 7.21).

Comparative analysis to other description systems. The purely image-based analysis parallel to the experiment described in Section 7.2 generally explained a smaller proportion of variance (R^2 from 24%, enclosure, to 83%, obtrusiveness, see Table 7.8). Concerning the actual regressor variables, several direct correspondents between global mean color values and wall color properties were found. Additionally, the total length of image edges (detected via a Laplacian-of-Gaussian algorithm) occurred several times in the regressor lists. In contrast to the image-based analysis, isovist measurands as described in Section 7.4 alone generally explained a smaller proportion of variance of all rating categories except of spaciousness (here explained variance R^2=63%). However, they apparently complemented the purely image-based measurands well: A regression analysis combining both description systems explained a similar proportion than the architectural elements based approach (R^2 from 43%, beauty, to 85%, obtrusiveness, see Figure 7.9). Notably, all sets of regressor variables comprised both pictorial and isovist measurands.

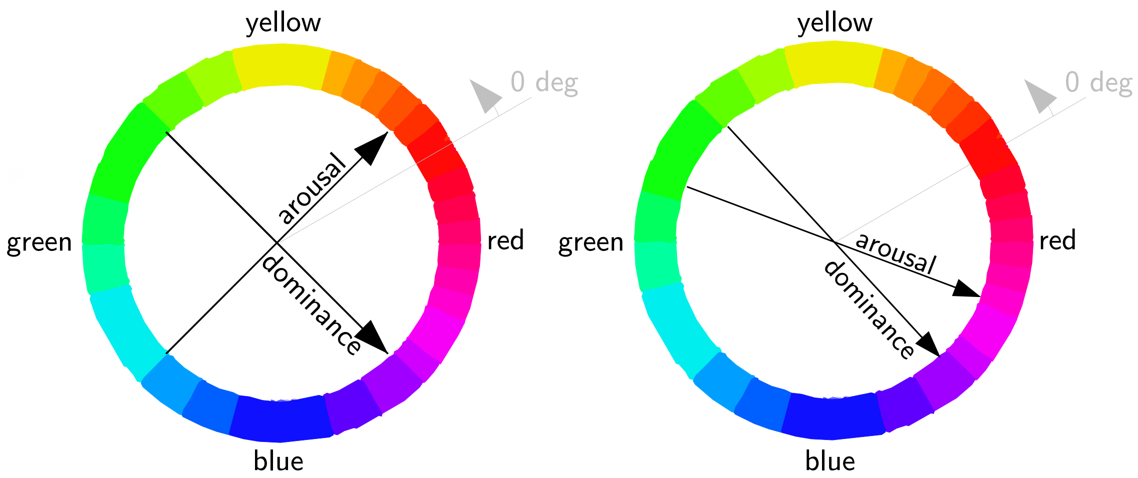


Figure 7.21: Predicted (left) and measured (left) correlation maxima between wall color hues and affective responses. The emotional dimension arousal was approximated by the mean of the rating categories excitement and interestingness, dominance by the mean of obtrusiveness and gravity.

Rating category	**Explained variance R^2**	**Regressor variables**
pleasingness	0.50	saturation L$\alpha\beta$ α, length image edges
beauty	0.33	std L$\alpha\beta$ α, length image edges, std brightness
excitement	0.75	saturation L$\alpha\beta$ α, std fft, std L$\alpha\beta$ β
interestingness	0.42	HSV saturation
obtrusiveness	0.83	saturation L$\alpha\beta$ α, std L$\alpha\beta$ β, brightness, HSV hue 165
gravity	0.51	brightness, saturation L$\alpha\beta$ α
spaciousness	0.52	length image edges, L$\alpha\beta$ α, mean fft, std L$\alpha\beta$ L
enclosure	0.24	length image edges

Table 7.8: Overview results of image-based multivariate linear regression analysis, abort criterion p_{max}=0.05.

Rating Category	Explained variance R^2	Regressor variables
pleasingness	0.54	saturation L$\alpha\beta$ α, length image edges, isovist perimeter length
beauty	0.43	std L$\alpha\beta$ α, length image edges, std brightness, proportion visible space at 8 m distance, isovist convexity
excitement	0.77	saturation L$\alpha\beta$ α, std fft, std L$\alpha\beta$ β, proportion visible space at 4 m distance
interestingness	0.48	HSV S, clustering coefficient
obtrusiveness	0.85	saturation L$\alpha\beta$ α, std L$\alpha\beta$ β, mean brightness, isovist jaggedness, HSV hue 164, number of isovist vertices
gravity	0.70	mean brightness, isovist revelation, length closed isovist boundaries, image edges verticality
spaciousness	0.72	second order neighborhood size, length image edges, isovist revelation, image edges verticality, std L$\alpha\beta$ L, proportion isovist bounding polygon
enclosure	0.51	length image edges, proportion visible space at 8 m distance, length closed isovist boundaries

Table 7.9: Overview results of the combined isovist- and image-based multivariate linear regression analysis, abort criterion p_{max}=0.05.

7.5.6 Discussion

Interaction / integration of different factors. Generally, the results fitted well to the hypothesized linear superimposition of factors from different architectural design aspects: In all rating categories significant linear terms both capturing pictorial and spatial properties were found. In direct comparison, color properties appeared to be tendentially more influential on the ratings than spatial properties. With respect to this study, this may be explained by the subjectively different degree of variability of the two factor categories: While room features were varied within the ranges of normal buildings, colors were systematically varied with respect to the HSV color space, thereby including several values rather unusual for architectural indoor spaces. Nevertheless, although the relative effectiveness of colors compared to spatial form cannot be derived from this experiment, its outcomes clearly suggests that color is indeed a constructively simple yet efficient means to influence the overall ambiance of architecture. It is particularly remarkable that wall color luminance also significantly affected the two spatial rating dimensions spaciousness and enclosure.

Color hue analysis. All in all, one has to be very cautious in generalizing the actual found color hue maxima: Besides the (consciously accepted) low level of control, also potential context effects have to be taken into account: Since all rooms shared the same wooden floor and white ceiling, it is rather probable that the ratings also reflect to some degree their relation to the wall colors.

As to be expected from the literature (cf. Section 6.3.2), all significant correlations between affective appraisals and color hues were found in the arousal and dominance related rating dimensions (see Figure 7.21). While the correlation maxima of the dominance rating categories gravity and obtrusiveness fitted very well to the predicted hues (from bright-light to dark-intensive), the observed correlation maxima of the arousal rating categories (excitement and interestingness) did not correspond to the assumed cold-to-warm color relation (corresponding to the central axis cyan-orange), the position of both maxima was clearly shifted towards green-pink. While it has to be stated again that the experiment was not designed to differentiate reliably between color nuances, one can nevertheless assume that arousal and dominance were not clearly independent in this experiment. One tentative explanation could be based on the relatively short exposure times that maybe did not allow for clear differentiations between the two aspects of affect. Unfortunately the experiment does not allow for any further predications whether long-term, presumably more physiological, effects would be more conform to the cold-warm scheme.

Comparison to previous experiments. In comparison to the widely similar (except of the varied wall color) experiment described in Section 7.3, it is noteworthy that all regressor variables of the previous experiment appeared again in this study apart from room area. A glance at individual linear correlations of room area however revealed that the data contained several significant correlations between room area and rated affective qualities (e.g., correlation coefficient to spaciousness $r=.83$, $p<.001$, enclosure $r=-.55$ $p<.001$, beauty $r=.31$, $p=.02$, pleasingness $r=.33$, $p<.01$). All of them correspond well to the outcomes of the previous study. Hence, the differences in the regressor sets can be mainly ascribed to the slightly different regressor selection strategies: In the precedent study, the set of regressor variables was manually selected in order to obtain simple, well-interpretable results. Whereas in this experiment the regressor variables were selected purely by statistical criteria, due to the different experimental question. Yet in contrast to Study 2, no evidence for nonlinear relations to room proportions could be found in this experiment. It remains unsolved whether this probably smaller effect was just widely masked by the various additional factors, or whether the precedent finding was mainly an artifact, or even a peculiarity of white or monochrome rooms.

Regarding the initial image-based study (see Section 7.2), also here a good level of correspondence can be found. Again the importance of overall brightness/luminance, saturation levels, and the usefulness of the simple edge detection algorithm were clearly supported. It is not really surprising that the overall proportion of explained variance using the same analysis as in the first experiment was smaller. Also the apparent unsuccessfulness of isovist measurands alone seems not too unexpected. It is rather worth mentioning that a combination of these two bottom-up analysis methods already explained together a similar good proportion of variance as the architectural elements based approach. The application of them has the considerable advantage of depending solely on uncategorized raw data without any semantic meaning that can be easily obtained from automatic detectors.

Overall explained variance. In comparison to the previous studies, the proportion of overall explained variance was smaller in particular in the affective rating categories. Several explanations are possible. One reason could have been the different experimental design: The web-based questionnaire did not control for constant experimental conditions, and participants used different and completely non-calibrated display devices. A further source of variance was the almost between-subject experimental design. All participants saw only a relatively small fraction of the overall scene set. Since affective appraisals are substantially influenced by the context (Russell, 1988), and all subjects saw different scene sets, each participant may have used a different internal scale. A further support for this noise-level hypothesis comes from a comparison of the variance within and between the scenes (see Figure 7.20): The proportion of explained variance was tendentially lowest in rating categories that had a small variance between the scenes, in other words, a high level of similarity with respect to a rating criterion made it more difficult to detect small effect sizes reliably. Since in this study much more physical factors were varied than in previous, it could be expected that each single factor contributed to a smaller degree to the overall variance. Additionally, the large proportion of explained variance in the previous studies could also be to some degree an artifact of their much smaller numbers of stimuli: The chances for random correlations in small scene sets is much higher than in larger ones, in general, 16 data values are much better fittable by three linear factors than 64. In sum, it seems well arguable that the still substantial proportion of explained variance in this study was closer to the actual real-world proportion caused by the measured physical factors, instead of assuming that the chosen predictor variables did not include some central physical properties. If one assumes an additional proportion of variance in the affective ratings explainable by further physical factors not accounted for in this analysis (e.g., topology/composition of architectural elements), the measured values clearly support Stamp's (2000, p. 134) conclusion that affective qualities such as beauty is rather out there than a matter of subjectivity.

7.5.7 Conclusion

Study 4 investigated the interaction and integration of different properties (spatial and pictorial) influencing affective responses to architectural environments. The multivariate linear regression analysis found for all rating dimensions linear terms from both physical categories. Hence, the hypothesized linear superimposition of the factors is a reasonable assumption for normal cases.

Additionally, the predictive power of the previously developed description systems for environmental properties were compared. Here the architectural elements based model appeared at first glance slightly superior to the other analysis methods. However, a combination of global pictorial image features and isovist-based spatial descriptors turned out to be similarly effective as the initial model. Methodologically, this approach has the advantage of not requiring any semantic information, the necessary environmental data can be completely obtained from "dump" data sources such as laser range scanners and digital panorama cameras.

In sum, the detected regressor variables corresponded very well to the previous studies and basically approved their findings. Also this more comprehensive study demonstrated that affective responses can be related to measurable properties of architectural environments. The substantial level of consensus among people allows to predict the affective qualities of architecture from already a few measurands.

Chapter 8

Comparative discussion

8.1 Introduction

This chapter serves two purposes: On the one hand, it compares the experiments presented in Chapter 7 to each other. On the other hand, the probable general implications but also the limitations of the studies are discussed. In order to allow a verbally tight discussion, the four experiments will be abbreviated by their ordinal number Study 1 to Study 4.

First Section 8.2 analyzes the studies synopticly on further global factors that initially arise from the experimental procedure. Then in Section 8.3 the comparative discussion initially started in Section 7.5.6 is continued including all four exploratory studies. Finally, Section 8.4 interprets the findings of the single studies with respect to the general framework outlined in Chapter 2 and 6. Vice versa, the initial framework are updated according to the empirical findings.

8.2 Meta analysis

8.2.1 Introduction

In this section, the experiments of the previous chapter are analyzed for global order and local sequence effects initially arising from the experimental procedure. This kind of factors is supposed to influence affective appraisals generally. Their relevance is first seen in their assumed contribution to the overall variance in the data that has not been explained by the specific analyses presented in the previous chapter. But most essentially, their influence on experiments is assumed to be roughly parallel to actual real world phenomena.

To test exemplarily for the assumed influences, the rating results of the experiments were subjected to a meta-analysis. Both hypothesized global order and local sequence effects relate to the temporal sequence of the stimulus presentation. From information theory related concepts (cf. Section 6.4.3), several temporally dependent mechanisms can be derived. If this holds true, it should be detectable in global order effects in the ratings. Second, the perception and experience of architecture is assumed to be considerably context dependent (Russell & Lanius, 1984). The context of the experiments was on the one hand the experimental setting itself, which remained constant over the experiments, but on the other hand also the scenes shown previously. Hence, it was hypothesized that in particular the antecedent scene might affect the experience and rating of the current stimulus. Please note that, although these types of effects were expected to be found in the ratings, their influence on the averaged ratings over all subjects (which were the basis of the analyses of the previous chapters) was considered to be negligible, because a complete and partially even balanced randomization of the sequences compensated for them.

8.2.2 Global order effects

Introduction. All experiments take a certain amount of time, and, even under well-controlled constant laboratory conditions, several factors change over time. First, there is a certain temporal dynamics of the situational context. While, for example, the way to the lab is initially still present, this context gradually fades during the experiment and becomes replaced by the ongoing experience of the experiment itself. Second, one can assume that the internal emotional state of participants changes over time, for example, from heightened interest to fatigue, or from arousal to a matter of routine, boredom, or even oversaturation. Hence, particular order effects on arousal related rating dimensions were expected. Analogously, as reported in Section 6.4.3, several information theory related concepts of environmental perception (Berlyne, 1960; Mehrabian & Russell, 1974) suggest indirect relations to the valence dimension via their novelty, predictability, or information rate qualities. Furthermore, as regards denotative experiential categories, sensory adaptation processes could be possible.

The existence and the coarse direction of such time dependent tendencies were explored tentatively by correlating the appraisals with their temporal sequence.

Method. For the meta-analysis, the ratings were z-transformed for each scene, now encoding individual deviations from the average rating of a scene. The rating sequences were averaged over all participants, the resulting scene-independent average values were correlated with their order rank. Linear Pearson's product moment correlation coefficients and significance levels were calculated using the GNU Octave mathematics software package.

Results. In both experiments that consisted of two independent sessions, the overall trends were consistent between the sessions, so the data was pooled for further analysis. As apparent from the charts on the left-hand side of Figures 8.1, 8.2, 8.3, and 8.4, some considerable trends and a few significant and partially strong correlations specific for single experiments were found (most prominently correlation coefficient to rated dynamics r=0.79** in Study 1), but no obvious overall trends became apparent.

Discussion. The strikingly strong order effect in the image-based experiment on rated dynamics is puzzling at first glance. Since this factor also possesses the largest variance (cf. Figure 7.3), it can be speculated that the general uncertainty about the concept was particularly initially, high while in the course of the experiment participants became more and more familiar with the admittedly abstract concept of dynamics in static stimuli and therefore had a stronger tendency to rate higher scores. Similarly, the strongly significant tendency (r=-.53**) to rate the stimuli of Study 4 less obtrusive over time could be tentatively explained by a certain familiarization of participants to the relatively strong and therefore obtrusive wall colors (cf. Figures 7.18 and 7.19): In addition, as derivable from Russell & Lanius (1984) and Russell (1988), initial ratings may reflect to a stronger degree an absolute scale, while later ratings were rather done in relation to the scene sets. The same habituation mechanism could be also assumed for further significant correlations (Exp. 1 warmth r=.52*, Exp. 2 brightness r=.50*), although here the relation to the underlying factor is less obvious.

The inconsistency over the experiments was surprisingly high and seemed to be more than just a result of noisy data. If this assumption were true, one could say that global order effects are very context specific. One factor that may account for the opposite tendencies between the experiments could be the different degrees of diversity within the scene sets. For example, in Study 2 only a few parameters were varied, and no or rather slightly negative trends in the valence related rating dimensions could be observed. Whereas in the first image-based study positive tendencies were clearly prevalent. Here the relative novelty of each scene was highest. This analysis, therefore, could indirectly support the positive valence of diversity in environments, although, of course, the exceptionally monotone context of laboratory experiments has to be considered. Finally, a further factor that could explain the differences between the studies was the absolute duration of the experiments, which differed from 25 minutes to 40 minutes on average. According to the post experimental interviews, the latter was already really fa-

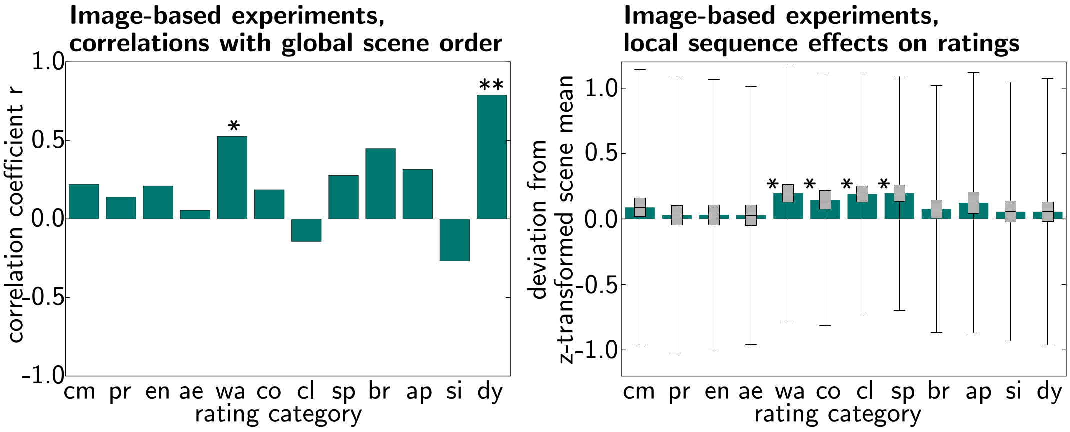


Figure 8.1: Meta analysis: global order (left) and local sequence effects (right) in the image based experiments. In all data plots of this chapter a single asterisk (*) indicates a null hypothesis probability of 5% to 1%, double asterisks (**) signify a probability below 1%. The rating categories were comfort (cm), privacy (pr), enclosure (en), aesthetics (ae), warmth (wa), complexity (co), clarity (cl), spaciousness (sp), brightness (br), appreciation (ap), simplicity (si), and dynamics (dy).

tiguing. For this reason, the number of rating categories was reduced in later experiments.

Conclusion. The existence of partially strong order effects could be demonstrated empirically. The phenomenon itself seems to be heterogeneous, an interpretation according to the diversity/novelty hypothesis is possible, yet not entirely mandatory. As done in these studies, empirical experiments should at least use completely randomized or even balanced scene sequences to compensate for these factors.

8.2.3 Local sequence effects

Introduction. In reality, architecture is never experienced in isolation. As a normally stationary structure, it is embedded in a unique context. Furthermore, ways of access are limited, leading to few fixed sequences of spaces. Since ancient times, architects have been well aware of this, they obviously made deliberately use of it, particularly for sacral and representative buildings (e.g., Egyptian temple complexes, cf. Joedicke, 1985). One handy basic means of architectural expression is the use of contrasting opposites (e.g., light versus dark, spacious versus narrow) to mutually increase their expressivity. Already Russell & Lanius (1984) and Russell (1988) investigated this effect empirically in particular for emotional experiences. They found systematic shifts in the ratings in the circular emotional space that were in accordance with the general adaptation-level the-

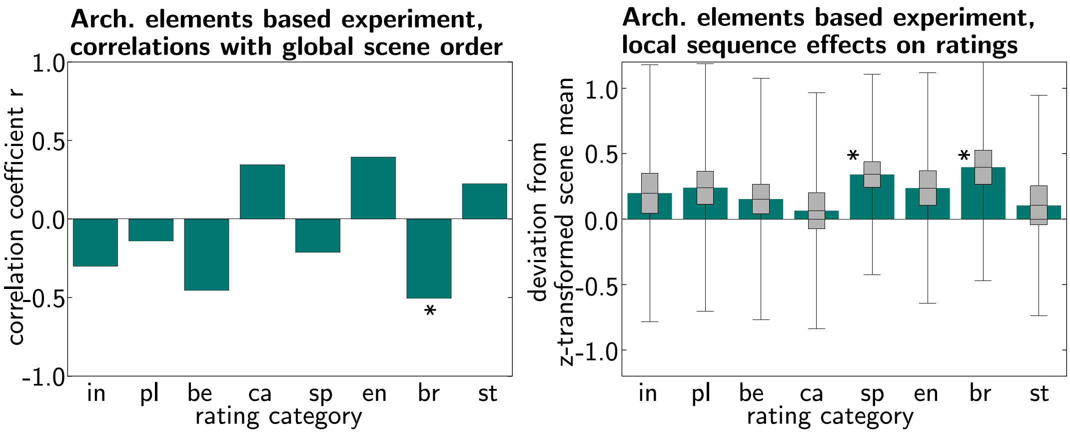


Figure 8.2: Meta analysis: global order (left) and local sequence effects (right) in the architectural elements based experiments. The rating categories were comfort (cm), privacy (pr), enclosure (en), aesthetics (ae), warmth (wa), complexity (co), clarity (cl), spaciousness (sp), brightness (br), appreciation (ap), simplicity (si), and dynamics (dy).

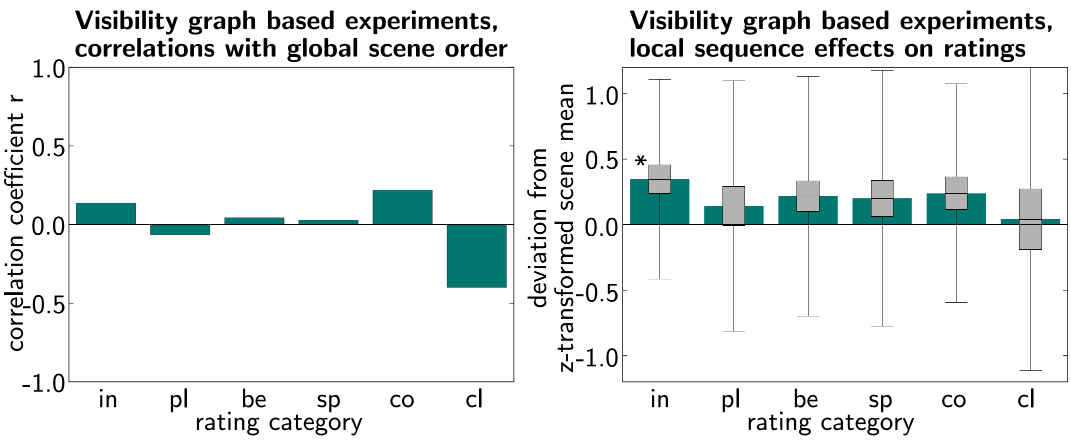


Figure 8.3: Meta analysis: global order (left) and local sequence effects (right) in the visibility graph based experiments. The rating categories were interestingness (in), pleasingness (pl), beauty (be), spaciousness (sp), complexity (co), and clarity (cl).

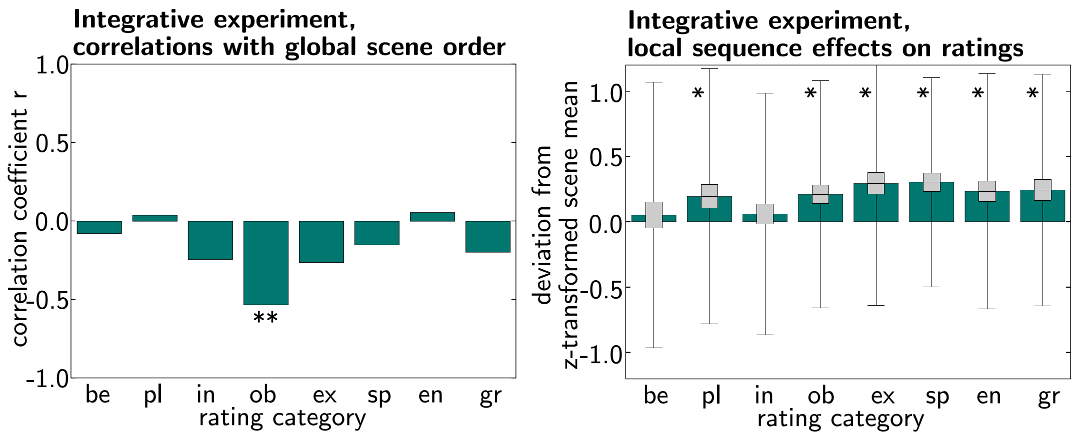


Figure 8.4: Meta analysis: global order (left) and local sequence effects (right) in the integrative experiment. The rating categories were beauty (be), pleasingness (pl), interestingness (in), obtrusiveness (ob), excitement (ex), spaciousness (sp), enclosure (en), and gravity (gr).

ory (Helson, 1964). Since the experiments described in Chapter 7 varied only few parameters in partially wide ranges, local temporal sequence effects were very likely to be found in the ratings.

The experiments which had been already carried out provided enough data to test for direct sequence effects. Since the ratings comprised affective, collative, and denotative categories, the meta-analysis allowed a comparative investigation of this phenomenon also for non-affective experiential dimensions that were not covered by Russell & Lanius (1984).

Method. The exploratory analysis concentrated exemplarily on effects of extreme values. In a first step the ratings were averaged and z-transformed. Any stimulus featuring an absolute rating mean z-score of larger than 1.0 standard deviations was treated as an extreme scene with respect to that rating category. Similarly, the individual ratings were z-transformed for each scene, now encoding individual deviations from the mean rating of a scene. The individual rating sequences were scanned for direct sequences of an extreme value followed by a scene where the mean rating had an oppositional tendency. Once identified, the individual z-scored deviation from the average scene rating was stored. Any sample whose mean value exceeded twice its standard error was treated as significantly different from the basic population (corresponding null hypothesis probability $p<0.05$).

Results. The right subfigures of Figures 8.1-8.4 illustrate the results of the analysis graphically as boxplots of the z-transformed deviations. Generally, while only a subset of the averaged deviations was significant, over all experiments and rating categories the tendential direction of the deviation was in accordance with the hypothesis without exception. The absolute size of the effects was moderate (deviation means < 0.4 SD), no specific differences between the superordinate rating categories (affective, collative, denotative) became apparent. Likewise, no consistent relative power for single rating dimensions over multiple experiments were found.

Discussion. In principle, the observed effects can be explained by several underlying mechanisms: For example, low-level sensory adaptations, shifts of the rating scales, or the wish to at least express a difference but having only a discrete scale at disposal, as well as the relativity of perception and experience come into question. The data do not really allow for a clear decision between the alternative explanations. At least against the sensory adaptation hypothesis the objection can be raised that this mechanism should be mainly effective in certain perceptual rating dimensions such as brightness, whereas other concepts should be widely unaffected. The consistent uniform trend speaks against this explanation as single cause.

Concerning the differences between the experiments, it can be argued that they were partially caused by the different durations of the intervals between the presentations of the stimuli. These breaks were initially technically motivated due to the necessary upload time of larger amounts of graphics data, but were later kept deliberately to give participants short recreational phases during the single trials. For this reason, their actual duration was under control of the subjects. Their minimal time span varied over the experiments, and in the web experiment additional variance was introduced by differences in the speed of the internet connections. Apart from this, the duration of an interval was on average at least 10-15 seconds, and during this time a uniformly dimmed blank screen was presented. Together with the relatively small dynamic contrast range of the presentation media, this experimental procedure allows to widely exclude the direct physiological after-effect hypothesis.

Alternatively, Russell & Lanius (1984) describes this effect mainly from a perspective of a “relativity of judgments” that are supposed to be obvious in affective appraisals. However, while this is a plausible factor contributing to the effect, it can be argued that this explanation alone which emphasizes the role of the experimental task may miss an important aspect of the phenomenon: As briefly mentioned in the introduction, contrasts are a widespread artistic means of expression to increase the effect of designs that have been used in practical architecture in all times. Hence, it is very likely that the phenomenon is more than just a shift of the personal rating scale, but reflects real differences in the actual experience of a situation.

Conclusion. This meta analysis provided convincing empirical evidence for direct sequence effects in affective appraisals of architectural spaces. In all rating categories, the observed tendencies corresponded to the hypothesized pattern intensification caused by contrast. Therefore, when evaluating the affective qualities of a particular piece of architecture, its context should be carefully considered. While the observed effects were predominantly moderate, mainly non-significant tendencies, the results do by no means degrade the actual relevance of this factor. Since the experimental design of presenting rooms as individual single stimuli rather counteracted its effectiveness, context and sequence effects in reality are probably much stronger than rendered by these studies.

8.3 General comparison

Introduction. The studies presented Chapter 7 explored relations between affective responses and physical properties of architecture. Each experiment concentrated on different design aspects and used a specialized description system to provide comparability and to capture especially the differences between the scenes. Parallelly, the scene sets were designed to feature maximal variance with respect to the investigated factors, and to be widely similar in other aspects. Unsurprisingly, the analyses found different sets of regressor or predictor variables.

At first glance, the studies therefore appear rather isolated from each other, and a direct comparison seems difficult. However, all studies shared similar dependent variables and the general approach of deriving the independent variables directly from the stimuli according to objectively specifiable criteria. Since the tested predictor variables were not just arbitrarily and subjectively selected, but actually targeted on capturing specific assumed underlying mechanisms (see Chapter 6), also the theoretical explanations of the detected relations offer a starting point for a comparative analysis. In addition, the integrative Study 4 exemplarily provides quantitative data from all description systems for one particular scene set. Based on these foundations, this section seeks to compare and partially integrate the single findings in an interpretative yet argumentatively backed manner.

Specific strengths and weaknesses of the approaches. Compared to each other, the three different description systems had specific advantages and drawbacks. The initial image-based approach of Study 1 did apparently very well in capturing qualities commonly associated with ambiance and atmosphere, i.e. global lighting and color properties. On the other hand, in its initial form the image-based analysis was completely dependent not only from the chosen observation

Experiment	Valence	Arousal	Dominance
image based	comfort	dynamics	privacy
	warmth	complexity	
	appreciation		
arch. elements based	pleasingness	interestingness	(openness)
	beauty	calm	
isovist based	pleasingness	interestingness	(enclosure)
	beauty	complexity	
integrative	pleasingness	interestingness	obtrusiveness
	beauty	excite	gravity

Table 8.1: Overview on the conceptual attribution of rating categories of the four studies of Chapter 7 to the primary dimensions of emotion. Terms in parentheses denote categories that capture some partial aspects of the emotional dimension, but are seen as too remote for an approximate equation.

point but also from the gaze direction. At least the latter could be easily overcome by using 360° panoramic images as in the comparative analysis of Study 4.

The most distinctive property of the architectural elements based approach of the Studies 2 and 4 was its potential to account for the semantic and functional logic of structural parts making up architectural space. The use of element lists also implicated a relative independence from single observation points. Nevertheless, the particular observation point was incorporated as relative spatial coordinate. In particular the extended version as used in Study 4, also including surface properties, appears to be a powerful model that integrates diverse aspects of architectural indoor space. However, the dependency on semantic information implies also considerable drawbacks: In contrast to the other approaches, the underlying data structure is currently not easily automatically obtainable from real-world spaces, but depends heavily on human assistance. Even if one has a digital model available, this does not guarantee that the respective information is conveniently accessible or at least semantically included. Hence, the general feasibility of this analysis in broader studies cannot be taken for granted. Second, the relative success of this approach was reached by accepting severe formal limitations: It is unclear how to extend the method to capture properties of non-rectangular forms.

Here lies the particular strength of the isovist-based approach of Study 3. Similar to Study 1, the analysis was completely bottom-up and could be done on the basis of relatively low-level data such as pure 2D or 3D geometry. Even point clouds

Experiment	Varied properties	Constant properties	Regressor variables affective qualities
image based	all	-	RGB red proportion
			HSV saturation
			amount of edges
architectural elements based	numbers & dims. of arch. elements	rectangular forms	openness
	fenestration	surface properties	room area
		surroundings	room proportions
isovist based	spatial form in horizontal section	spatial form in vertical section	isovist area
		architectural elements	enclosure ratio
		surface properties	isovist jaggedness
		illumination	number of symmetries
			number of (different) segments
integrative	numbers & dims. of arch. elements	rectangular forms	wall color $L\alpha\beta$ α saturation
	fenestration	surroundings	openness
	wall color		room proportions

Table 8.2: Overview on the studies presented in Chapter 7, varied properties and detected regressor variables for the affective rating dimensions.

of laser range scans appear principally suitable. Although also the isovist-based descriptions used in this study did not capture topology, they apparently considered many important characteristics of spatial form indirectly. Also the potential of visibility graph analysis to integrate beyond single observation points is a clear advantage of this approach. An integration of non-spatial or non-formal properties, however, appears non-trivial. Hence, isovist-based analyses appear rather specialized on spatial form and configuration and seem to require a complementation by other measures.

Correspondences. Table 8.2 provides a synoptic overview on the experiments and a selection of the observed most occurring predictor variables for the affective rating dimensions (cf. Table 8.1). There are several direct correspondences between the different experiments: The room proportion measurands in Study 2 are the same as the room proportion measurands in Study 4, and room openness from Study 2 and 4 corresponds to enclosure ratio of Study 3. Also global HSV saturation and RGB red proportion of Study 1 have substantial overlap with wall color saturation in the L$\alpha\beta$ α dimension from Study 4. Furthermore, isovist area (Study 3) and room area together with openness (Study 2) are clearly related; the amount of image edges (Study 1) and the number of isovist edges or isovist jaggedness (Study 3) probably capture similar aspects. Additionally, there are a few less obvious but well explainable further relations, for example between the pictorial brightness measurand of Study 1 (not in the list, since its main correlations were to perceived brightness and clarity) and room openness from Study 2 and 4 (illumination through windows), and even to isovist area from Study 3, since in this experiment the light source was the entire area of glass ceiling. The outlined parallels are further backed by the comparative analysis of Study 4 (see Section 7.5.6).

Based on this comparison, it seems justifiable to strongly reduce the total number of detected widely independent main regressors to about 7 basic factors (color hue, color saturation, number of edges/features, openness, area, proportion, and symmetry). All of them were detected in more than one experiment, which to some degree supports their validity and likely general importance. Furthermore, they can be well explained by existing theories that relate affective responses to physical properties: Color hue and saturation correspond to the physiological effects ascribed to color, the number of features fit well to information theory related concepts, as well as proportions and symmetries that additionally are in accordance with traditional normative architectural knowledge. Openness and absolute dimensions can be derived from the spatial form related theories, and even in the Pattern Language obvious parallels to all factors can be found. It is remarkable that all initially reviewed theories (see Chapter 6) are at least partially covered by this small set of factors, although one should be cautious in drawing too extensive conclusions, since an analysis can only reveal factors that are entered.

Limitations. Further predications on the completeness of this factor list, or on their relative importance would be of course desirable, but cannot be derived from the conducted exploratory studies. It seems clearly worthwhile to address both questions in future experiments whose hypotheses can be based on the interpretations of this section (see Section 9.4).

Conclusion. Although the exploratory studies presented in Chapter 7 used incommensurable systems for describing the physical properties of the scenes, several parallels between their predictor variables became apparent. Taken together, a quite small set of underlying core factors can be assumed. Since a generalization of the findings of these limited experiments is clearly speculative, one should express the interpretive main message of this section positively: A description system that aims at covering the major physical factors influencing the affective experience of architectural indoor spaces should include measurands that somehow capture the following properties:

- overall color tone and intensity
- absolute dimensions
- space proportions
- degree of complexity
- order patterns
- openness of the space boundary

With respect to these criteria, none of the initially developed specialized description systems alone can claim to completely capture the emotion-affecting properties of architecture, but they likely offer a useful basis for more comprehensive description systems (see Section 9.3). Furthermore, the strong parallels between completely unrelated analysis models suggest a promising robustness of the general approach against differences regarding the underlying data raising method. This may allow an adjustment of the measurands to particular requirements of a study without necessarily sacrifying overall comparability.

8.4 Implications on the framework model

Chapter 7 has explored various physical properties or design aspects of architectural indoor spaces and their relations to affective appraisals. Based on this, in the previous section a tentative set of main factors has been identified. This section now takes a question a little farther that has been already touched in Experiment 4 (Section 7.5), the integration of different factors in coherent affective responses. The question is of central importance for the real world validity of single-factor studies, since potentially interactions with non-controlled factors could completely compromise their predictive power. These considerations suggest a strong demand for an integration of single findings into a more generic model and leads back to the basic theories and to the conceptual framework that has been preliminarily raised in Section 2.7.

Unfortunately, most existing models of environmental psychology (cf. Section 2.5) appear inappropriate to derive respective overall predications, since they are either specialized partial theories or centered on individual behavior and stay rather vague concerning particular interactions of environmental factors. At least from Lewin's field theory (1982, see Section 6.4.1), a clear predication can be derived, provided that multiple field vectors are possible for the same physical stimulus or space that may be caused by different aspects. In this case, the theory indeed suggests that the response would be a sum of the individual vectors.

Influenced by the field theory, the basic proposition initially expressed in Formula 2.2 is that affective responses are the result of various factors that somehow together determine the overall result. Given that all factors except of one were constant, functional relations could be directly observed by comparing varied stimulus and affective response. While this coarse, cautious, and admittedly vague framework was originally the basis of the exploratory studies, the experimental and analytical design was implicitly based on extended assumptions: All experiments investigated effects of groups of somehow related factors simultaneously and analyzed for identifiable linear relations within the varied feature space. In other words, instead of only assuming affective responses as a function of several factors, the analysis tried to explain the variance in the ratings by a *sum of factors*. However, the framework model allows also quite different overall relations such as for example the product of factors. The basic general linear model (GLM) of statistics, which was applied within the restricted scope of groups of related factors or design aspects, basically assumes that overall results are an outcome of an additive superimposition of many linearly independent partial factors. Also further central aspects of the methodological approach are rooted in this statistical model, namely the summarization of individual responses to affective qualities.

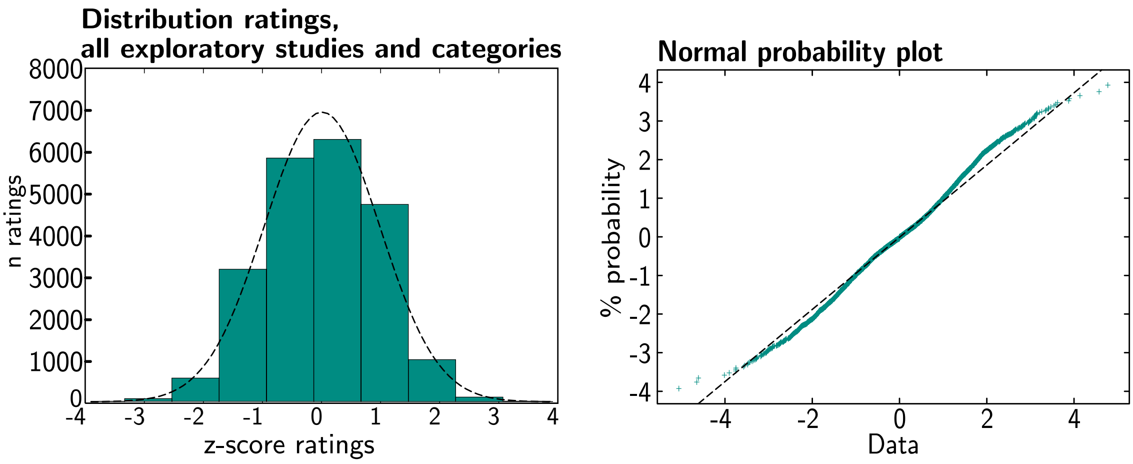


Figure 8.5: Histogram and normal probability plot of all z-transformed ratings done in the exploratory studies. Altogether, 23484 data values were raised. The distribution significantly differs from a normal distribution (dashed line), but shares its overall characteristics.

Indeed the general picture conveyed by the three initial studies focusing on single factor groups is widely in accordance with the GLM. Almost all regression analyses of ratings found more than one significantly contributing independent variable, and the overall proportions of explained variance could not be achieved just by single factors. For further exploring the interaction of factors beyond the initially chosen vague limits of design aspects, Study 4 was designed. Also the results of this experiment were in accordance with the now hypothesized model. Additionally, the comparative analysis (Section 8.3) demonstrating parallels over non-related experiments support this model. So, together the findings of the experiments of this dissertation project truly suggest that the GLM has been a reasonable assumption for the factor-analysis studies.

A further line of argumentation in favor of the GLM can be drawn based on the fact that affective population responses to architecture as a whole tend towards normal distribution. This observation is well backed by comprehensive empirical studies (Russell, 1988; Stamps, 2000). As illustrated in Figure 8.5, also the sum of all samples drawn in this thesis share the general characteristics of the Gaussian distribution, although there are significant differences (Anderson-Darling test p=.01, probably due to the discrete rating steps and the restricted rating range which despite z-transformation limit the range of potential distributions). With respect to the initial framework model, the summarization of individual responses corresponds to a summarization of a certain group of factors ("individual differences"). The span of this factor group is at second glance much more comprehensive than obvious from the catchphrase: Conceptually they arise to a substantial proportion from differences in the perception, evaluation, and weighting of stimulus properties. Hence, already in the individual factors, physical or environmental properties are interwoven. Since the approximately normal distribution of sample responses can be best explained by the GLM, this strongly supports its transfer also on physical properties.

However, besides the general objection that still all experiments together comprised a limited and unbalanced set of factors, there is also some evidence that speaks against the universal validity of the GLM. For example, in everyday language rooms were often characterized by only one obviously outstanding or dominant feature (cf. Section 2.4). Similarly, one interpretation of the results of the first stage of Study 3 (Section 7.4) can be the assumption of a dominance effect of only one feature. Furthermore, the findings of de Kort, Gal, & Staats (2004) can be interpreted as indications for the existence of global moderator variables: When studying the effects of the presence or absence of people in photographs of outdoor environment, they found that the effectiveness of this factor and direction of its influence depended on the category of environment (forest, park, village). So one could tentatively generalize this and assume that the combination of physical and social environmental factors may be rather an interaction than a simple super-imposition. Additionally, the theories briefly reported in Section 6.4.1 suggest that in particular actions could be a global moderator variable that might be capable to determine the influences of environmental factors in a non-linear way. The demand of subjects for a defined function as observed in Study 3 (cf. page 134) can be interpreted accordingly.

Nevertheless, while individual relations could be under certain circumstances much more complex, when regarding the overall picture, the general linear model (GLM) appears to be a reasonable preliminary assumption that fits very well to existing theories and to the current state of empirical knowledge. It has the big advantage of being simple, intuitive, and allows actual real world predications already based on findings from restricted case studies. And, of course, it is a basis for specific hypotheses that can be empirically tested in future studies that either approve it or successively contribute to a more refined general model.

8.5 Summing up

In this chapter, the exploratory studies presented in Chapter 7 were synopticly analyzed and compared, and some implications on the general picture were drawn. Most prominently, a minimal set of likely generally emotion-affecting properties of architecture was proposed comprising the recurring primary factors of the exploratory studies. Furthermore, arguments in favor of the general linear model as preliminary framework for the interaction and integration of various factors were presented. While both statements are basically working hypotheses, they nevertheless appear useful as best currently available basis for applied studies, and offer concrete starting points for further specific fundamental research.

Chapter 9

Epilog

9.1 Summary

Architecture has an emotional impact on humans. Although it is a common experience that there are rooms where one immediately feels comfortable and perfectly at ease, whereas others appear repelling or even menacing, the general topic is still only vaguely understood, and architects lack a well-founded knowledge on the basic relations. The overall goal of this dissertation project was to provide a basis for investigating affective responses to architectural indoor spaces empirically. Hence, several constituent core issues were addressed that together should allow for a systematic comparative analysis of relations between physical properties and affective responses:

- The operationalization and quantification of affective responses using the concept of affective qualities based on models and findings of environmental psychology.
- The development of a practically applicable factor-analytic experimental methodology that transfers aspects of psychophysical methods on architectural stimuli using virtual reality simulations.
- The quantitative description of architecture by generically applicable measurands that capture a wide range of behaviorally and experientially relevant physical properties of architecture.
- A framework model on the interaction and integration of different independent design aspects together contributing to the overall experience which fits well to the current state of knowledge.

The empirical approach was not only overall aim of this dissertation project, but also the primary methodical means during its genesis. All in all, the various empirical studies that have been done (see Chapters 5 and 7) clearly support the general approach of treating affective qualities conceptually as an objectively determinable quality of architecture that allows to predict a large proportion of individual affective responses.

9.2 In retrospect

The foreseeable end of the written dissertation, and also the hopefully temporally close completion of the general thesis project, has provoked the author to some notions and remarks on the general approach. Of course, in retrospect and in relation to the final outcomes, several aspects of the practical work appear in a different light as compared to the initial perspective. When starting the dissertation in the mid of 2001, only the coarse topic and direction was clear. Most generally, one presumably always wishes that the constituent steps would have been done a little bit more concise, and that the final scope and framework would have been fixed earlier. Although the general relevance of the technically oriented conducted studies presented in Chapter 5 is clearly arguable, with respect to the main focus they appear to some degree as a secondary sidestep. However, to the author's mind a complete avoidance of the topic "transferability" would have severely affected the overall convincingness of the approach as a whole, yet the main conclusion of these studies that in itself consistent deviations do not affect the external validity of relative predications should have been drawn earlier.

Regarding the exploratory Studies 1, 2, and 3 presented in Chapter 7, larger sample sizes appear clearly desirable in retrospect, because they would substantially support the relevance and general validity of the findings. A well-organized work plan provided, moderately larger studies appear indeed feasible with hindsight. However, it has to be taken into account that the - sometimes lucky - early success of the exploratory studies could not be taken for granted in advance, therefore the direct progression to further subproblems appeared to be most rational when considering the substantial breadth of the overall topic and formulated objectives.

In particular for the comparative analysis, an early selection of a consistent set of rating dimensions for all forthcoming experiments would have been advantageous. With respect to that and several further aspects, rather an antecedent than a parallel literature review would have been useful. This however and several minor methodological shortcomings can be partially ascribed to the author's initial non-scientific academic background. On the other hand, the approach of the topic from the unusual direction of architectural practice opened up slightly different and hopefully sometimes fresh perspectives that can therefore also be seen as strengths.

9.3 Implications

Despite the preliminary character of the studies and many unsolved and hardly touched questions, the dissertation project may nevertheless provide some useful novel insights into various topics. The following section draws - optimistically - some implications on the disciplines that in some form contributed to or were touched by this project.

Architectural simulation / VR setup design. Overall, the studies convey the impression that the capabilities of current consumer-grade graphics hardware are in principle already sufficient for useful architectural simulation. The number of polygons that can be handled in realtime seems to offer enough geometric detail for the limited needs of rather small-scale interior simulations. Yet, since the studies have also highlighted the particular relevance of lighting and surface properties for affective qualities, realtime computer graphics development should continue focusing on pictorial quality. Here a particular necessity is seen for improving the general ease of use, for example by optimizing the work flow concerned with "atmospheric" realism tweaking light, colors and materials. While current technical solutions (e.g., programmable hardware shaders) are in principle very powerful, they do not meet the requirements of practically oriented users. More intuitive, maybe high-level parametric material models similar to ray tracers would be clearly desirable to open up the technically available potential also to non-computer aficionados. Pointing in the same direction, a better integration with computer-aided architectural design (CAAD) software would be very helpful (Donath & Loemker, 2000). While these software packages are in principle very powerful to generate models, their completely different data structures make it currently very difficult to generate effective realtime visualizations. Hence, also the internal databases need to become much more flexible.

Concerning the relative suitability of different VR simulation setups, the conducted preliminary studies do not allow conclusive predications. Generally, the necessary technical demands appear fairly moderate, since even desktop and web-based experiments rendered well interpretable and plausible results. To the author's view, the of course desirable further refinement of simulation setups is all in all far from trivial, since more elaborate high tech simulators often also increase the artificiality of the situational context, a factor which may be directly affecting the general experience. Hence, with respect to simulating affective qualities, a particular focus on intuitively usable and non-obtrusive setups and simulators appear desirable. A promising respective direction of development is outlined in Section 9.4, Paragraph "architectural free space walking".

When introducing novel simulators, experimental procedures similar to the ones described in Section 5.5 appear to be generally useful for calibrating particular setups before using them for architectural simulation. For such technical purposes also the stimuli generation method briefly presented in 5.6 seems generally useful.

Perceptual psychology and cognitive science. Several individual findings of this dissertation support the assumption that already basic percepts have the potential to elicit various affects directly that may in turn influence behavioral responses. In particular the discipline of spatial cognition may gain further insights from the fact that already mere physical structure is affectively laden, suggesting influences on spatial navigation behavior. And beyond this merely qualitative statement, the findings of the conducted experiments provide concrete hypotheses concerning several physical properties, indeed all the tentatively identified primary qualities affecting emotional responses appear worthwhile to be tested on further influences on behavior. The general approach described in this thesis may be useful to base respective research on a quantitative fundament, and also non-emotional oriented studies may benefit from the developed and tested generic description systems.

Analysis of affective qualities / architectural psychology. Naturally, the most obvious relations can be drawn to the field this work is situated itself. While the generalization of all individual observations can at best be done very cautiously, they nevertheless offer the chance to start just one small step further than this project. Academic studies may on the one hand consider the results of the conducted studies as hypotheses for further, probably more comprehensive, experiments. On the other hand, they may benefit from the developed methodology combining psychophysically inspired experimental procedures and virtual reality simulations as well as particularly from the basic description systems to capture behaviorally relevant properties of environments and the framework model.

Architectural theory and education. In general terms, architecture as a discipline should critically yet constructively question its basic fundamentals that - if apparent at all - are often rather normative or conceptual than rationally explicable. Both the synoptic review of related research and the conducted experiments during this dissertation strongly supported the initially hypothesis that affective influences are relevant and objective qualities of architecture. The particular relevance of this aspect lies in its well-arguable foundation in biological and psychological processes. Therefore, an adequate consideration of affective qualities in the architectural design process appears to be more than just another possible perspective, but as a response to an objective need human beings have with respect to their environment. Consequently, it seems appropriate to consider the general topic and even the fragmentary current state of knowledge more centrally in the academic education of future architects. Several approaches seem possible, ranging from the quantitative analysis of existing buildings, over the integration of affective qualities as additional evaluation criterion in design studios, to the consideration of basic rules in textbooks and lectures.

Additionally, the implications of the concept of affective qualities may help to settle the still sometimes heated scholar debate between normative and subjectivistic perspectives on architectural design: Empirical investigations provide conclusive evidence and even quantitative data for both a substantial level of communality between people as well as for individual differences. Generally, the empirical point of view and its methodological basics appear to be fruitful complementations for the curricula opening an additional perspective on architectural questions. Architecture as academic discipline has the great strength of spanning from arts, humanities to technical and social sciences. A stronger emphasis of its foundation in natural empirical sciences may help to overcome the current state of relative passivity and stagnation, leading to a positive development of the general discipline towards a comprehensive human-centered applied science engaged in the further development of the environment according to some general basic principles.

Architectural practice. From the outlined general direction, also practicing architects may benefit in future. In recent years architecture as a profession has got deeply into defensive, at least in Germany an increasing share of a diminishing absolute volume of new buildings is built without architects. Particularly in the mass market architects have difficulties to argue for their standpoints in a further industrialized building process. Since the ongoing specialization and diversification of the building and planning process more and more challenges the traditional comprehensive role of architects, they sooner or later will need to acquire additional competences in order to strengthen their position. The particular consideration of human factors in building design seems as a suitable natural focus complementing their technical and organizational abilities, updating and reestablishing their traditional aesthetic and human-centered design competences. And, by making use of reliable simulation and approximate quantification methods, particular design decisions may become positively and objectively arguable, strengthening the position of the architects and their concerns in the dispute with others representing differing interests in the planning and building process.

Vice versa, the explicit and even quantitative definition of suitable experiential and affective qualities as design goals for new buildings by future users and owners may help to satisfy their needs more comprehensively. Since affective qualities can be approximatively quantified in advance using affordable simulation techniques, already nowadays design decisions or competition entries can be evaluated before they are built according to this specifiable criterion (Nasar, 1999).

While one long term goal of the initiated research is to make affective qualities of architecture predictable, it shall be clearly stated that the overall aim is to be descriptive and not prescriptive. The author sees affective qualities basically as one often disregarded design dimension that is, from an architects' point of view, definitively worthy to be further explored and extended in a creative manner.

9.4 Proposed further research

Direct follow-ups. All in all, the thesis touched various disciplines and raised a wide range of different questions. Not all of them could be answered, and most answers given were preliminary or not completely conclusive. Hence, from the author's point of view, a deepening and broadening of almost all conducted studies appears highly desirable. Furthermore, there are various architectural design aspects that could not be covered by the restricted number of possible experiments. For example, the influences of furnishing, exterior context / vistas, complete spatial form including ceiling and floor, or defined function could not be investigated, but would have integrated organically into the overall scope. Additionally, if the author had the possibility, he would strive for a further integration of so far individually analyzed architectural dimensions. Also from an analytical point of view, a systematic improvement and extension of the description systems would be highly interesting, for example a consideration of the third dimension in isovist measurands, or the integration of topological information in the architectural-elements based description. So, with regard to the initial scope and still persistent interest, it would be easy to at least double the volume of this dissertation. Fortunately, complete exhaustiveness was not a primary objective.

Architectural free space walking. A concrete integrative follow-up project having a comprehensive scope similar to this dissertation could be the development and implementation of a technical setup allowing for true free-space walking in simulated architecture. This project would be a response to the demand for more natural and intuitively usable simulators as formulated in Section 9.3 and would allow a continuation of many questions only superficially touched in this thesis. It would have a strong technical direction and thereby allow an investigation of various open setup-related questions concerning architectural simulation, for example the influence of the physical field of view (cf. Section 5.5.3), of (un-)restricted ego-motion (cf. Section 5.5.4), or of auditory simulation on general simulation validity. At the same time, these originally technically oriented questions would address aspects relevant for architectural perception in general, for instance the influences of peripheral vision or auditory qualities on the experience of spaces. Furthermore, the project would offer the opportunity to explore almost natural spatial behavior on correlations with affective responses, thereby possibly opening an unobtrusive alternative data source complementing and substituting introspective verbal techniques (cf. Section 3.2). Finally, purely architectural questions such as the context dependency and the influence of the spatio-temporal sequence on the experience of architecture could be directly investigated (cf. Section 8.2.3), provided that free-space walking laboratory would allow the simulation of small-scale spatial environments consisting of several rooms, that then could be explored freely and experienced very similar to reality.

General directions. The few ideas briefly presented in the previous paragraphs all sticked more or less to the initial scope of the dissertation of a survey-like exploration of relations between features of indoor spaces and affective responses. Yet with regard to the overall topic, various different more general directions of research appear worthwhile.

Quite closely related, but far beyond the scope of this dissertation would be the investigation of quantitative relations between physical properties and representative population samples. This kind of research could be highly valuable due to the universal practical relevance of its findings, but also may lead to further insights into individual differences, and may allow implications on the biological or cultural foundations of the observable communality. Probably such an investigation would also require some form of real world statistics of spatial situations, and even intercultural comparisons, in order to determine the overall baselines affective appraisals or even responses are apparently subjected. Furthermore, the availability of quantitatively reliable data would allow a substantial refinement of the framework model. In terms of the preliminarily proposed general linear model, for example, the relative weights of the individual design aspects could be determined.

Methodologically, the systematic enhancement of alternative data raising methods approximating affective responses that are not based on introspective verbal techniques could open up completely novel insights into the general phenomenon. Here, the potential main difficulty could be the reaching of a similar level of differentiation as verbal techniques offer at virtually no effort, and the sustain of consistency between methods. These foreseeable problems demand for a better and truly comprehensive theoretical framework on emotion in general.

A further line of theoretically oriented research may aim at broadening the - deliberately - restricted scope of this project beyond architectural indoor space. Ideally, future theories comprise equally the experience also of natural and artificial outdoor environments.

Finally, at least a basic knowledge on long-term effects and the actual real-world relevance of affective qualities of architecture would be highly desirable. Clearly, a wide range of possible results are possible, ranging from basically irrelevant, over mainly a matter of luxury, social status or self-esteem, to a basic constituent of human psychical and physical well-being (cf. Section 2.8). While scientific seriousness naturally demands for such an open-ended non-anticipating approach, it should be obvious that this dissertation has been written with belief in the actual relevance of the topic. More than three years of respective studies were a great opportunity to diversify the overall personal conception, but clearly corroborated this positive general conviction.

Appendix A

Documentation scene descriptors

This appendix documents in more detail the scene descriptor variables of the central experiments presented in Chapter 7. The given mathematical formula allow a replication of the analysis, and also inner relations between the variables (via the variable names) can be derived. Furthermore, since the text in Chapter 7 concentrates on the presentation and discussion of significant effects, the following sections allows an overview on the recorded scene data in their entirety including also the variables that did not render significant results, or that were not discussed because strongly interrelated scene descriptors rendered higher correlations.

A.1 Image-based study

The following global image descriptors were calculated for Study 1 (Section 7.2) using the GNU Octave mathematical software package:

Variable	Calculation method	Description
mean brightness	$mean2(\frac{R+G+B}{3})$	The *mean2* function computes the two-dimensional mean of a matrix. *R*, *G*, *B* denote the red, green, and blue RGB values of the individual image pixels.
std brightness	$std2(\frac{R+G+B}{3})$	variance brightness. The *std2* function computes the two-dimensional standard deviation of a matrix.
RGB red	$\frac{mean2(R)}{mean2(\frac{R+G+B}{3})}$	RGB proportion red
RGB green	$\frac{mean2(G)}{mean2(\frac{R+G+B}{3})}$	RGB proportion green

Variable	Calculation method	Description
RGB blue	$\frac{mean2(B)}{mean2(\frac{R+G+B}{3})}$	RGB proportion blue
mean HSV S	$mean2(S)$	saturation
mean YIQ Y	$mean2(Y)$	brightness or luminance
mean L$\alpha\beta$ L	$mean2(L)$	brightness or luminance
mean L$\alpha\beta$ alpha	$mean2(\alpha)$	hue red-green
mean L$\alpha\beta$ beta	$mean2(\beta)$	hue yellow-blue
std L$\alpha\beta$ L	$std2(L)$	variance luminance
std L$\alpha\beta$ alpha	$std2(\alpha)$	variance red-green
std L$\alpha\beta$ beta	$std2(\beta)$	variance yellow-blue
amount of edges	$mean2(edge(\frac{R+G+B}{3},'log'))$	Method 'log' for function *edge* means a Laplacian-of-Gaussians convolution filter, the standard deviation of the filter was 2 pixels.
verticality	$\frac{\Sigma\left|conv2(\frac{R+G+B}{3},'prewittV')\right|}{\Sigma\left|conv2(\frac{R+G+B}{3},'prewittH')\right|}$	Function *conv2* is a two dimensional convolution filter. The 'prewittV' convolution filter was implemented as follows: $\frac{1}{3} * \begin{bmatrix} 1 & 0 & -1 \\ 1 & 0 & -1 \\ 1 & 0 & -1 \end{bmatrix}$. The 'prewittH' convolution filter was implemented as follows: $\frac{1}{3} * \begin{bmatrix} 1 & 1 & 1 \\ 0 & 0 & 0 \\ -1 & -1 & -1 \end{bmatrix}$.

A.2 Architectural elements based study

The following room descriptors in Study 2 (Section 7.3) were directly provided by the SceneGen tool (cf. Section 5.6):

Variable	Description
sizeX	room size X
sizeY	room size Y
sizeZ	room height
camWallX	distance wall X - observation point
camWallY	distance wall Y - observation point
nWindows	number of windows
windowW	window width
windowH	window height
balustrade	window balustrade height
nDoors	number of doors
doorW	door width
doorH	door height

The following combined room descriptors were calculated for Study 2 (Section 7.3) using the GNU Octave mathematical software package:

Variable	Calculation method	Description
propLW	$\frac{max(sizeX,sizeY)}{min(sizeX,sizeY)}$	proportion length/width
propLH	$\frac{max(sizeX,sizeY)}{sizeZ}$	proportion length/height
propWH	$\frac{min(sizeX,sizeY)}{sizeZ}$	proportion width/height
volume	$sizeX * sizeY * sizeZ$	room volume
area	$sizeX * sizeY$	room area
sizeOneWin	$windowW * windowH$	size single window
areaAllWin	$windowW * windowH * nWindows$	area all windows
aWinPerRoomVol	$\frac{areaAllWin}{volume}$	area all windows divided by room volume
aWinPerRoomArea	$\frac{areaAllWin}{area}$	area all windows divided by room area
openness	$\frac{areaAllWin}{sizeZ*2*(sizeX+sizeY)}$	area all windows divided by wall area
propWindow	$\frac{windowH}{windowW}$	proportion window height/width
nWindowsOpt	$\|nWindows - 5\|$	deviation from 'optimal' number of windows
sizeOneDoor	$doorW * doorH$	area single door

A.3 Isovist based study

The following table gives an overview on the measurands used in the isovist based Study 3 presented in Section 7.4.

Variable	Calculation method	Description
neighbors		neighborhood size, isovist area
neighbors2		second order neighborhood size, area visible from current neighborhood
clustering	$\frac{n\ intervisibilities\ neighbors}{neighbors(neighbors-1)}$	clustering coefficient, intervisibility

Variable	Calculation method	Description
revelation		absolute revelation
perimeter		isovist perimeter length
open		length open isovist edges
close		length closed isovist edges
pc0angle		angle of first principal component of isovist
pc0minExt		short extension of first principal component of isovist
pc0maxExt		long extension of first principal component of isovist
pc1minExt		short extension of second principal component of isovist
pc1maxExt		long extension of second principal component of isovist
boundingProp	$\frac{l_{first\,principal\,componenent}}{l_{second\,principal\,componenent}}$	proportion of bounding rectangle
nVertices		number of isovist polygon vertices
visRatio2		free near space ratio, proportion of visible graph vertices at distance 2 m
visRatio4		proportion of visible graph vertices at distance 4 m
visRatio6		proportion of visible graph vertices at distance 6 m
visRatio8		proportion of visible graph vertices at distance 8 m
nSymAxes		number of symmetry axes
nPolySects		number of isovist polygon segments, in principle identical to *nVertices*, but evaluated manually
nDiffPolySects		number of different isovist polygon segments
regularity		mean score regularity ranking

Variable	Calculation method	Description
perimeter2Area	$\frac{area}{{l_{perimeter}}^2}$	roundness
convexity	$\frac{roundness}{bounding\,proportion}$	convexity, roundness normalized by overall proportion
openness	$\frac{l_{open\,isovist\,boundaries}}{l_{closed\,isovist\,boundaries}}$	isovist polygon openness ratio
revelCoef	$\frac{revelation}{neighbors}$	revelation coefficient
pc0Excent	$\frac{pc0minExt}{pc0maxExt}$	excentricity reference point along first principal component
pc1Excent	$\frac{pc1minExt}{pc1maxExt}$	excentricity reference point along second principal component
excentricity	$pc0Excent * pc1Excent$	overall excentricity of reference point
nbhDivNbh2	$\frac{neighbors}{neighbors2}$	proportion first/second order neighborhood size
nVrtxPerPerim	$\frac{nVertices}{perimeter}$	average isovist boundary polygon vertex distance
nVrtxPerArea	$\frac{nVertices}{area}$	isovist boundary polygon vertex density
nDiffSectsRel	$\frac{nDiffPolySects}{nPolySects}$	proportion of different isovist polygon segments
nSymDivNSects	$\frac{nSymAxes}{nPolySects}$	relative proportion of symmetries
nSectsDivNSym	$\frac{nPolySects}{nSymAxes} + 1$	relative proportion of asymmetries
nSymDivNUniqSects	$\frac{nSymAxes}{nDiffPolySects}$	relative proportion of symmetries in relation to the number of different isovist polygon segments
irregularity	$\frac{nDiffPolySects}{nSymAxes} + 1$	calculated polygon irregularity

A.4 Integrative study

The integrative study presented in Section 7.5 made use of the same description systems and variables as described in the previous sections. In addition, the initial architectural elements based analysis made use of following descriptors:

Variable	Calculation method	Description
winSashes		number of horizontal window sash bars
winBeams		number of vertical window beams
wallR		wall color RGB red
wallG		wall color RGB green
wallB		wall color RGB blue
wallH		wall color HSV hue
wallS		wall color HSV saturation
wallV		wall color HSV value
wallL		wall color L$\alpha\beta$ luminance
walla		wall color L$\alpha\beta$ alpha (red-green)
wallb		wall color L$\alpha\beta$ beta (blue-yellow)
LabAAbs	$\lvert walla \rvert$	wall color L$\alpha\beta$ alpha (red-green) saturation
LabBAbs	$\lvert wallb \rvert$	wall color L$\alpha\beta$ beta (blue-yellow) saturation
rgbRExc	$\lvert \frac{wallR}{wallR+wallG+wallB} - \frac{1}{3} \rvert$	wall color proportion RGB red
rgbGExc	$\lvert \frac{wallG}{wallR+wallG+wallB} - \frac{1}{3} \rvert$	wall color proportion RGB green
rgbBExc	$\lvert \frac{wallB}{wallR+wallG+wallB} - \frac{1}{3} \rvert$	wall color proportion RGB blue
hue0-hue179		wall color HSV hue linearized in 180 bands

Appendix B

Academic curriculum vitae

Gerald Franz

Date of birth December 30th, 1974 in Göppingen, Germany.

School graduation June 1994 Abitur (i.e. high school diploma) at the Helfenstein-Gymnasium, Geislingen / Steige, Germany. Focus in mathematics, arts, English, and religion.

Graduate studies 1994-2001 twelve semesters architecture and urban planning at the University of Stuttgart, Germany.
1999 one semester at the Technical University of Vienna (Austria) within the Erasmus academic exchange programme.
April 2001 Diploma university degree (corresponding to master's degree) in architecture from the University of Stuttgart. The Diploma project "Festo BioTecLab" was a design of an educational and exhibition center in the city of Esslingen, Germany. It was supervised by Professor Karla Syszkowitz-Kowalski.

Post-graduate studies Since August 2001 PhD thesis project at the Max Planck Institute for Biological Cybernetics, Tübingen, Germany.
Supervisors: Dr. Markus von der Heyde and Prof. Dr. Heinrich H. Bülthoff.
Title: An empirical approach to the experience of architectural space.
Since August 2003 Mentorship by Prof. Dr. Dirk Donath, Bauhaus University Weimar, Germany.
April 2005 submission of this dissertation and application for defense and graduation.

Appendix C

Ehrenwörtliche Erklärung

[Statement of authorship]

Ich erkläre hiermit ehrenwörtlich, dass ich die vorliegende Arbeit ohne unzulässige Hilfe Dritter und ohne Benutzung anderer als der angegebenen Hilfsmittel angefertigt habe. Die aus anderen Quellen direkt oder indirekt übernommenen Daten und Konzepte sind unter Angabe der Quelle unmmissverständlich gekennzeichnet.

Bei der Auswahl und Auswertung folgenden Materials haben mir die nachstehend aufgeführten Personen in der jeweils beschriebenen Weise unentgeltlich geholfen:

- Die Konzeption, Durchführung, Auswertung und Dokumentation der empirischen Studien beschrieben in den Abschnitten 2.4, 5.4, 5.5.1, 5.5.2, 7.2 und 7.3 erfolgte in Absprache mit Dr. Markus von der Heyde und Professor Dr. Heinreich H. Bülthoff auf Basis des Betreuungsverhältnisses am Max-Planck-Institut für biologische Kybernetik, Tübingen.

- Die Konzeption, Durchführung, Auswertung und Dokumentation der empirischen Studien beschrieben in den Abschnitten 7.4 und 7.5 erfolgte in Absprache mit Professor Dr. Heinreich H. Bülthoff auf Basis des Betreuungsverhältnisses am Max-Planck-Institut für biologische Kybernetik und mit Professor Dr. Dirk Donath als betreuender Mentor an der Bauhaus-Universität, Weimar.

- David Zauner, Dr. Markus von der Heyde und Dr. Jan M. Wiener unterstützten die Ausarbeitung des Manuskripts durch sprachliche Korrekturen.

Weitere Personen waren an der inhaltlich-materiellen Erstellung der vorliegenden Arbeit nicht beteiligt. Insbesonders habe ich hierfür nicht die entgeltliche

Hilfe von Vermittlungs- bzw. Beratungsdiensten (Promotionsberater oder anderen Personen) in Anspruch genommen. Niemand hat von mir unmittelbar oder mittelbar geldwerte Leistungen für Arbeiten erhalten, die im Zusammenhang mit dem Inhalt der vorgelegten Dissertation stehen.

Die Arbeit wurde bisher weder im In- noch im Ausland in gleicher oder ähnlicher Form einer anderen Prüfungsbehörde vorgelegt.

Ich versichere ehrenwörtlich, dass ich nach bestem Wissen die reine Wahrheit gesagt und nichts verschwiegen habe.

Weimar, im April 2005

(Gerald Franz)

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