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Developments in Research Design, Data Collection, and Analysis

QUANTITATIVE METHODS

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Recent methodological developments in environment–behavior research, as in the behavioral sciences, have evolved from new conceptualizations of phenomena and relationships, and from a slow withdrawal from analytic simplification. Conceptualizations incorporating time and those of transactional or contextual frameworks (Altman & Rogoff, 1987) have demanded new approaches to empirical study. In addition, the nagging question, "are we measuring what we think we are measuring," posed by scientists as well as by phenomenologists, the media and the courts has prompted consideration of new methods of inquiry.

Oftentimes this recognition has led to "qualitative versus quantitative" debates, not only in the environment–behavior field but also in organizational behavior, program evaluation, history, sociology, and feminist studies. True dichotomies are rare and it would be an oversimplification to think that methods of gaining knowledge can be classified into two distinct camps. Choice of method is based, consciously or not, on one's assumptions about the nature of knowledge,

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how that knowledge can be obtained, and about the nature of the phenomenon itself.[1] Morgan and Smircich (1980) have developed a typology of methodologies, based on a continuum which reflects ontological and epistemological assumptions behind different methodological approaches. We agree with their notion that empirical research involves a continuum of methods that cannot be easily grouped, but from which a stratum can be bounded by similar underlying assumptions about the nature of the phenomenon and the nature of gaining knowledge about it.

In this chapter we discuss such a stratum which (a) assumes that reality is something concrete and can be experienced, defined, and discussed; (b) employs an instrument external to the researcher which is used to collect information about that reality or one's perception of it; (c) employs measurement, that is, the assignment of numbers to observable responses and conditions such that the numbers are amenable to analysis according to certain mathematical rules (Nunnally, 1970); and (d) assesses relationships among two or more variables.

Our intention is to describe recent developments of such methods in environment–behavior research. We use as benchmarks two texts, *Inquiry by Design* by John Zeisel (1981), and *Behavioral Research Methods in Environmental Design* by William Michelson (1975), which present various data collection techniques, as well as attempts by Lozar (1984) and Mandel (1984) to develop measurement taxonomies for the field.[2] In each of these reviews, the focus is on data gathering. However, we believe two additional components of methodology warrant attention. One is research design (i.e., the procedure of determining when, to whom, and how frequently the researcher applies data collection instruments and other possible interventions); the other is the analytical procedures for examining data. In the remainder of the chapter, we discuss recent developments using this tripartite framework.

DEVELOPMENTS IN RESEARCH DESIGN AND SAMPLING

The design of a study, including the procedures for selecting settings and individuals, influences the generalizability of the conclusions beyond the immediate setting and beyond the population under study (i.e., external validity). It also effects the likelihood that the findings may be attributable to alternative factors (i.e., internal validity). Quantitative research designs can be classified as experimental, quasi-experimental, and survey.

[1] In the real world, choice of method is also influenced by time and budgetary constraints imposed on the researcher.

[2] A revised edition of the Michelson book considers applications as well as descriptions of methods (Bechtel, Marans, & Michelson, 1987).

Experimental Designs

Experimental designs have been the backbone of the physical sciences and were prevalent in early laboratory research in the social and behavioral sciences. During the 1960s, as an environment–behavior focus emerged from related research concerns (Moore, 1987), and concerns about external and ecological validity became more pressing, the setting for many experimental studies was transferred to the "field" of naturally occuring environments. Whether in laboratory or natural settings, the essence of the design has been the same: a presumed "treatment" or independent variable is introduced to one group of participants but not to others, and the conditions and characteristics of those receiving and not receiving the treatment are assumed equivalent. Much of the experimental research in the environment–behavior field has concentrated on between-group designs, with infrequent use of within-group designs or more complex designs such as the Solomon Four group.[3] The designs have constituted an important segment of past research in the field, whether conducted in contrived settings (e.g., Desor, 1972), or in natural settings (e.g., Landesman-Dwyer, 1984). Yet no significant advances have been made using this design since the field has moved toward studies involving quasi-experimental designs and survey designs.

Quasi-Experimental Designs

There are two basic types of quasi-experimental studies: pretest–posttest nonequivalent control group designs and interrupted time-series designs.[4] For the former, comparisons between the effects of a treatment and its absence are made between nonequivalent groups, in conjunction with a pretest. With interrupted time-series designs, comparisons are made among the same subjects prior to and after treatment. In both designs there is a specified time when the treatment is introduced.

Nonequivalent Control Group Designs. These designs have had less applicability in the environment–behavior field, not so much because of the problem of identifying a comparable, though nonequivalent comparison group, but because pretest measures for both groups are difficult to obtain. For example, Kleeman's (1981) postoccupancy evaluation of a Federal Aviation Agency (FAA) office complex in Seattle considered comparable group data from another newly created FAA complex in Los Angeles. Both organizations were similar in the number of employees, job characteristics, and management structure. However, Kleeman

[3] This design is used to consider external validity factors and is discussed by Solomon (1949) and Campbell and Stanley (1963, p. 24).

[4] A distinguishing feature of quasi-experimental studies is that, unlike experimental designs, treatment and comparison groups are not randomly assigned.

was unable to obtain pretesting measures similar to the posttest outcome measures. Cook and Campbell (1979) suggest that proxy pretest measures can be used if they are highly correlated with the posttest measures, and if the pretest scores for the treatment and comparison groups are comparable.[5] If they differ, statistical techniques such as partial correlation tend to underadjust the effects, resulting in a possible significant treatment effect when none actually exists.[6]

A cohort design with treatment partitioning and random selection eliminates the necessity of gathering pretest measures for all participants. This type of design was used in assessing relocation decision making (Conway & Graham, 1982) and is shown diagrammatically below:

O (X) O	Inside boundary (prior)
X O	Inside boundary (proximate)
X O	Outside boundary (post)

where X represents the treatment or the introduction of the court-ordered busing, O represents observations or measurements of any kind, (X) is the presentation of the treatment irrelevant to the argument, and the dashed line (----) indicates that the groups above and below the line are nonequivalent.[7] The sample consisted of randomly selected recent movers to homes located outside an area subjected to court-ordered busing. The researchers investigated whether the households after the court order exhibited search procedures differently from one comparison group that searched prior to the court order and one group that searched during the court order. The three groups were labeled *post* (moved after court decision), *prior*, and *proximate* (moved during event).

Two exemplar studies using nonequivalent control group quasi-experimental designs took advantage of naturally-occurring setting change to assess the impacts of those changes on individuals. In a study of open plan offices, Oldham and Brass (1979) examined work satisfaction and job-related activities resulting from a change in office design. The experimental group consisted of employees who moved from conventional offices to open-plan offices. A nonequivalent control group consisted of employees who did not change offices. Questionnaires were administered once before the move, and twice afterwards. A "quasi-control" group was also incorporated in the study consisting of employees who moved

[5] The use of proxy pretest measures for a nonequivalent control group design is demonstrated in Moore (1986).

[6] We note that in addition to the need for a high correlation between the proxy measure and the posttest measure, construct validation between the two measures should exist. Two variables can be highly correlated, but if they represent different constructs, they may be differentially influenced by treatment factors.

[7] The figures depicting different research designs use the diagramming scheme established by Campbell and Stanley (1963).

from the conventional to the open-plan offices, but who were not administered a questionnaire before the move. This design, shown below, enabled the researchers to assess change in responses due to the exposure to the pretest instrument as well as to the move.

O X O O	Experimental group (conventional to open office)
O O O	Control group (no change)
X O O	Control group (conventional to open office)

A second study (Cohen, Evans, Stokols, & Krantz, 1986), diagramed below, considered the impact of aircraft noise and adaptation on elementary school children's blood pressure and attentional processes. Children living and attending schools in the air corridor of Los Angeles International Airport (Schools 1 and 2), and children of similar socioeconomic, age, and racial composition living and attending schools in quiet Los Angeles neighborhoods (Schools 3), were tested twice, 1 year apart, for blood pressure and task persistence to determine whether or not noise effects occurring during the first year persisted a year later. In the noisy schools located in the air corridor, some classrooms were renovated to abate noise (Schools 1). This renovation or treatment occurred after the initial tests were administered. By conducting the same tests in all classrooms a few months after renovation (i.e., comparing Group 1 against Group 2), the authors were able to assess the behavioral and physiological effects of the classroom renovation.

O X O	Schools 1 (noisy neighborhoods)
O O	Schools 2 (noisy neighborhoods)
O O	Schools 3 (quiet neighborhoods)

Interrupted Time-Series Design. The interrupted time series (ITS) design involves multiple observations of an outcome measure and a treatment or intervention occurring within this series of observations at specific points. This design is diagramed as:

O O O X O O O

The most basic time-series design is the simple interrupted time series which involves multiple observations before and after an intervention for a single group of individuals or units. Weinstein (1977) assessed the socializing and reading activities of children for several weeks before and after a physical change in a kindergarten classroom. This approach enabled her to examine the effects of maturation. However, she was not able to assess other threats to internal validity, particularly historical effects that may have occurred at the same time as the intervention.

In attempting to counter any treatment-correlated historical events from confounding the design, an ITS with multiple replications might be used. As shown in the diagram, a treatment is introduced, X, withdrawn, $\bar{X}$, introduced again, X, withdrawn, $\bar{X}$, and so on according to a predetermined schedule.

$$O \; O \; X \; O \; O \; \bar{X} \; O \; O \; X \; O \; O \; \bar{X} \; O \; O$$

A treatment effect would be assumed if a change in the outcome measure occurred similarly each time the treatment was applied, and also similarly each time it was withdrawn. Jason and Jung (1984) used this design to study whether or not a "handicapped-only" sign placed in front of a parking space deterred unauthorized use of handicapped parking spaces. Although a powerful design for inferring causal effects, ITS can only be used where the initial effect of the treatment dissipates quickly and where practically and ethically the researcher can withdraw and introduce the treatment.

Another type of ITS design enables a researcher to assess a treatment-correlated historical event as an alternative explanation. In evaluating a design modification in an open-plan high school, Evans and Lovell (1979) used the same basic design as Weinstein but added a "nonequivalent control group" (see diagram following). Concurrent with observations at the modified open-plan school (both prior to and after the intervention), observations were made at a high school that had similar educational philosophies, operations, and faculty, but where no design change or other interventions occurred.

O O O	X	O O O
O O O		O O O

Adding nonequivalent control groups is advantageous in allowing the researcher to assess alternative explanations such as history. For example, Schnelle, McNees, Thomas, Gendrich, and Beagle (1980) employed a multiple baseline ITS design using three nonequivalent samples to evaluate the effects of newspaper publicity on littering behavior.[8] This design (see diagram following) enabled the researchers to control for threats to internal validity, and strengthened external validity by demonstrating change with different samples and at different times.

[8]This design is also referred to as ITS with switching replications.

O O O	X	O O O		O O O
O O O		O O O	X	O O O
O O O		O O O		O O O

Survey Designs

Most quantitative research in the environment–behavior field incorporates a survey design,[9] that is, where the distribution of participants being studied is not controlled by the researcher and establishing causality between variables may not be a major objective of the study. Over the years, cross-sectional survey designs (survey at one point in time) and trend designs (cross-sectional surveys at different points in time but with different individuals participating each time) have been prevalent in the field. Panel designs, on the other hand, are relatively new and involve gathering data from the same individuals (the panel) on more than one occasion (Markus, 1979). Panels are most likely to be used in studies of change (e.g., residential mobility, child development, life-span development) or in studies assessing the stability of phenomena (e.g., memory, environmental attitudes).

In conjunction with structural modeling techniques discussed later in this chapter, panel studies have been used to assess relationships over time. Fitzhugh and Anderson (1980) conducted a panel study of 34 households, using two waves of data collection. Residents were interviewed 3 months apart in order to assess causal relationships between personalization, feelings about security, control, and residential satisfaction. Because factors like personalization, control, and feelings of security are difficult to experimentally manipulate, but of substantial practical and theoretical interest, the panel design enabled the researchers to uncover structural relationships among ecologically valid phenomenon.

The stability of attitudes has also been investigated using panel designs. Using three waves of survey data covering residents in 23 cities between 1977 and 1979, Varady and O'Toole (1984) were able to assess changes in perceptions of neighborhood conditions and the impacts of neighborhood revitalization on the elderly who remained in the neighborhood. In assessing the impact of change, the researchers compared data covering the elderly with those of the nonelderly living in the same neighborhoods. Similarly, panel data from HUD's housing allowance program were used by Ahrentzen (1986) to show that single-parent families, unsuccessful in their attempts to find a new home, changed their opinions about the residences in which they were obligated to stay.

[9]Throughout this chapter, the term survey refers to a design process rather than questionnaires or other instruments used to collect responses from study participants.

Adaptation, a physiological and behavioral construct incorporating a temporal perspective, has also been investigated with panel designs such as the one used by Cohen *et al.* (1986). However, the study, while advancing both theoretical and practical concerns, also displays an inherent difficulty in interpreting longitudinal data—selective attrition. In the noisy schools without a physical design change, elevated blood pressures among children occurred when they were first examined but not later. However, a relatively high proportion of the children with higher blood pressures was not included in the later panel because of school transfers. Consequently, the researchers were unable to accurately assess whether or not blood pressure levels habituate over time. Performance deficits on test puzzles among children at the noisy schools occurred at the time of the first panel, but not during subsequent observations. Again, this trend could be attributed to attrition bias, pretesting effects, or adaptation.

Research designs incorporating a longitudinal perspective are essential if theoretical frameworks are to incorporate a temporal dimension. Although resources for implementing panel designs are often prohibitive, established data bases such as those used by Ahrentzen and Varady and O'Toole, and others compiled by the federal government and university-based research organizations could be employed to address questions of relevance to environment–behavior researchers.

Sampling

The research discussed in this chapter has relied on quantitative data collected from many individuals in one or more settings. For the most part, the research was conceived so that findings could be generalized to similar settings or to others in the population. Few studies, however, fully discuss how settings and people were selected. Unless a particular setting was unique or few people were associated with the setting, the likelihood is that the selection involved sampling.

Fundamental to understanding sampling is the idea that it is often financially infeasible, logistically difficult, and wholly unnecessary to study each and every unit or element associated with a population (Kalton, 1983). In sampling terminology, the population is the totality of elements to which the researcher wants to generalize the findings. If the researcher were interested in office workers in a building, the population would consist of all workers in the building and the researcher would select a sample to study. Similarly, for researchers interested in places, samples could be selected from the populations of parks, neighborhoods, or office buildings in a city, or new towns in a country. Rather than generating data about each and every element in these populations, data would be collected for the sampled elements, analyzed, and, depending on the type of sample design, the findings would be generalized to the entire population.

Nonprobability Samples. One type of sample design that prohibits the generalizability of findings is nonprobability sampling. Nonprobability sampling has been used with regularity in person–environment research and involves the researcher's judgment in selecting a setting or in selecting subjects associated with a setting. For example, experiments aimed at understanding environmental perceptions often use students recruited from classes who are shown models or photographs of a setting or several settings and asked to respond to a series of questions (e.g., Schroeder, 1984). Judgments are made in both the selection of photographs considered to be representative of the settings and in selecting students as supposedly representative subjects.

Studies employing experimental designs also have used nonprobability sampling in selecting subjects. Individuals who volunteer or are drafted to participate in a study are assumed to be representative of the groups or populations from which they are drawn. Although one cannot generalize from the results of such studies to the entire population, this sampling approach is often the only practical way of obtaining subjects who then can be randomly assigned to an experimental group and a control group.

Another practical use of nonprobability sampling is illustrated by Michelson (1977) who studied families moving to residential settings in Toronto over an 18-month period. Lists of families were compiled with the aid of realtors' multiple listings and building managers. Families who met predetermined criteria of composition, age, and interest in particular sectors of the housing market were contacted. The relevant sectors were downtown apartments, suburban apartments, downtown single family houses, and suburban single family houses. Michelson planned a quota sample whereby 100 families entering each sector would be studied. Because of the unpredictable nature of the housing market, however, the actual number who participated ranged from 94 families in single family downtown locations to 286 families in high-rise suburban locations.

Michelson's selection of particular residential settings, his exclusion of others, and his focus on a single demographic group—married couples in the childbearing years with and without children—constitute a nonprobability sample. That is, the choice of settings and subjects are judgmental and therefore, study findings were not generalizable to other segments of the Toronto population wanting to live in other parts of the metropolitan area.

Probability Samples. Whereas researcher judgments were the basis for selecting settings in several environment–behavior studies, probability sampling often has been used to select people associated with those settings. In contrast to nonprobability sampling, probability samples yield estimates for population attributes that are free from researcher judgments or biases. Moreover, elements are chosen so that study findings can be generalized to the entire population from which the sample is selected.

The main approaches to probability sampling in the environment–behavior field are simple random sampling, stratified sampling, and cluster sampling.[10] For example, Appleyard and Carp (1974) selected a simple random sample of households within one mile of the BART system in San Francisco to study the impacts of noise, traffic, and other environmental changes on nearby residents. The University of North Carolina evaluation of new towns and their residents (Burby & Weiss, 1976) used cluster sampling to select households, and then within the chosen households, a random sample to identify residents to interview. Stratified sampling was used by Lawton and Nahemow (1979) who studied the impact of building characteristics on the well-being of older Americans. Questionnaires were administered to residents selected from a sample of federally assisted housing units, stratified according to size.

Whereas the Burby-Weiss study used a nonprobability sample to select new towns and then probability sampling to identify households and residents within each new town, Lawton and Nahemow employed a two-stage probability sampling design to first select housing units and then a respondent. Although the combined use of nonprobability and probability sampling has been used with regularity in environment–behavior research, multistage probability sampling to select both settings and people has occurred less frequently.[11]

The limited use of probability sampling in the field reflects, in part, the problem of obtaining or developing an accurate sampling frame or listing of all elements in the population. Whereas a list of classrooms in a school or students in each classroom can be produced with relative ease, creating a frame can be more difficult for other types of settings or populations. To illustrate, Moos and Lemke (1981) developed a frame using directories of state licensed community and health facilities, and of federally assisted housing, and from telephone listings in five counties in order to obtain a representative sample of various sheltered care settings in California. The frame was organized into three groups or strata consisting of skilled nursing facilities, retirement homes, and apartment buildings. Ninety-three settings were selected by probability methods from the three strata in proportion to their numbers in the total population of settings. Their approach to selecting sheltered care settings enabled the researcher to generalize their findings to other such settings in California.

Although advances in environment–behavior research during the past decade have been largely attributable to greater use of sophisticated research designs, contributions from sampling theory and practice have played an increasingly important role in the field. A greater understanding of the virtues of probability

[10]A complete discussion of probability sampling techniques is beyond the scope of this chapter. The reader is referred to an excellent primer on sampling (Kalton, 1983) and to Marans (1987) which describes probability sampling as it relates to environment–behavior research.

[11]See Kalton (1983) for a discussion of multistage probability sampling.

sampling along with the availability of computerized lists of people and places have prompted many researchers to consider this approach, thus extending the usefulness of their research beyond the context of the immediate setting and the population associated with it.

DEVELOPMENTS IN TECHNIQUES/METHODS OF DATA COLLECTION

In this part of the chapter, we focus on approaches to generating quantitative data for environment–behavior research. By quantitative data, we mean information about reality or concrete conditions and situations that can be defined and experienced. Moreover, the information is represented by numerical values assigned to the conditions and situations and to peoples' responses to those conditions and situations.

Much of the research in the environment–behavior field stems from Lewin's conceptualization of behavior (*B*) as a function of the person (*P*) and the environment (*E*) in which the person operates. Although measuring personal characteristics and behaviors has been central to the early research in the field, little effort was made to conceptually and operationally distinguish between the environment as reality and the environment as it is perceived and evaluated by its users. A review of EDRA proceedings through the early 1970s reveals a paucity of studies where quantitative data on the environment as reality are presented. However, studies where quantification of the environment in perceptual or subjective terms are abundant. In Lozar's (1974) review of methods, limited reference is made to collecting data about environmental reality. Measures of the physical environment such as light levels, thermal conditions, and noise are discussed, but only briefly and in the context of human responses.

Since the early 1970s, several writers have stressed the need for measuring environmental reality as well as peoples' perceptions of it (Marans & Rodgers, 1974; Moore, Tuttle, & Howell, 1985; Wohlwill, 1974). The challenge is being accepted by an increasing number of researchers. Quantitative data therefore includes "objective" or factual information about the environment as well as factual information about the people associated with the environment including their behaviors, and "subjective" information including peoples' perceptions and evaluations of the environment and their own situation (i.e., their well-being).

Collecting Objective Data

Whereas objective data reflecting the reality of a condition or situation can cover physical, organizational, or cultural attributes of settings, researchers in the field most often consider objective data on the physical environment. The physical environment has been conceptualized and measured both as a totality and as a bundle of discrete physical attributes each of which is considered separately. The patterns of Alexander, Ishikawa, and Silverstein (1977) are conceived as physical totalities and their categorization can be thought of as measures of total units. Similar views on the environment have been expressed by Bechtel (1977) who classifies physical settings as spaces for enclosing behavior. Others have conceptualized the environment in terms of discrete physical and nonphysical attributes, measured them separately and have examined their additive and interactive effects on various forms of behavior (Carp & Carp, 1982a; Marans & Spreckelmeyer, 1981).

One approach to measuring the physical environment is to classify it or its attributes into commonly understood and agreed upon groupings. That is, the reality of the situation is observed, measured, and recorded by trained observers, with or without the aid of mechanical instruments. For example, measures of lighting, temperature, air movement, ultraviolet emissions from building lamps, and noise have been made in laboratories and at workstations in office buildings (Fanger, 1970; Flynn, 1977; Sterling & Sterling, 1983). Similarly, technical measures of traffic counts and noise levels (Appleyard & Lintell, 1972) have been made in community studies.

A trained observer can also measure a situation by simultaneously observing and describing a particular attribute without mechanical instruments. For instance, employee workstations can be categorized by observers as conventional offices having floor to ceiling partitions and a door, open offices having low partitions, or open offices without partitions. Similarly, workstations can be classified as to whether or not there is a view to the outside from a sitting or standing position.

Observing and counting an attribute is also a form of measurement. The number of items within a workstation such as photographs of family members on walls, posters, plants and desk paraphernalia measures the extent to which the work has been personalized—a measure which not only describes and quantifies a particular attribute of the workstation, but characterizes the behavior of its occupant. Other examples of observed objective measures of environmental attributes include the number of steps from the sidewalk to the building entrance, and steps from the building entrance to tenant's rooms (Lawton, Brody, & Turner-Massey, 1978), distances between neighboring dwellings (Marans & Wellman, 1978), and the classification of the type of construction for transportation lines—subterranean tunnel, grade, earth molded, and aerial (Carp & Carp, 1982a).

In addition to observer-based objective environmental data collected directly at the site, indirect measurement using secondary sources have been used in environment–behavior research. Census data covering dwelling units or population size, together with census or other scaled maps, have been used to calculate residential density (Rodgers, 1981) while community maps and aerial photographs have been used to measure distances between residents' homes and playfields, open space, transportation lines and transit centers, and schools (Burby & Weiss, 1976; Carp & Carp, 1982b; Marans & Fly, 1981). Similar approaches have been used in building studies where floor plans and furniture layouts have been a source of information about space assigned to workers, worker density and distances between where people work and windows, stairways, and elevators (Marans & Spreckelmeyer, 1981).

Besides plans, drawings, and aerial photographs, other secondary sources such as police records, student–teacher ratios at local schools, and attendance records in offices have been a source of quantifiable data about the environment. These data describe the environment beyond the individual or what Lemke and Moos (1981) and Carp and Carp (1984) refer to as the suprapersonal environment. The suprapersonal environment or sociocultural environment (Connerly & Marans, in press) represent another set of conditions that can influence peoples' behaviors, and most typically have included characteristics of other people in the environment (i.e., the social surrounds of the individual). For example, community-based studies have measured population characteristics such as the proportion over 65 years old or nonwhite, household characteristics such as average monthly rent, or characteristics of housing for older people—age mix of residents, percent male, or religious background (e.g., Lemke & Moos, 1981; Rosow, 1967).

A third approach to obtaining data on the physical and suprapersonal environment is to ask subjects to indicate whether or not a particular condition exists. This approach is best used when the environment is intimately known and used by subjects—asking survey respondents how many bathrooms are in the housing unit and the number of television sets or automobiles they own. Questionnaires have also had workers indicate whether they are able to control office lighting and whether there is a computer terminal at their primary workstation (Marans, 1986).

Objective data about individuals is typically collected on attributes such as gender, income, ethnicity, and level of education. However, objective data covering people's physiological and behavioral characteristics have also been used in environment–behavior studies. For example, the environmental stress research encompasses measures on physiological conditions such as blood pressure, skin conductance, respiration rates, and muscle tension, and on behavioral characteristics by using checklists where respondents indicate specific activities they have performed (Evans & Cohen, 1987). Behavioral factors have been measured in relation to space and time by behavioral mapping techniques. Other methods of assessing behavior include time budgets or diaries which allow respondents to indicate not only the activities they engaged in throughout the day, but also the duration of those activities, and other contextual factors such as where the activity occurred and the presence or absence of other individuals (Michelson, 1985).

Collecting Subjective Data

As mentioned earlier, subjective data reflecting people's evaluations and perceptions have been quantified in much of the environment–behavior research. In fact, most studies in the field discuss the environment in purely subjective terms. In terms of advances, two can be reported. First, efforts have been made by researchers studying the same topic but operating in different settings to ask subjects the same questions or sets of questions. Questions and indices used in studies of housing and residential satisfaction in the United States have also been used in Canadian, Swedish, and Australian studies (Weidemann & Anderson, 1985). Similarly, questions dealing with tenants' preferences have yielded comparable results at different times and at different places (Michelson, 1977; Thorne & Turnbull, 1984) whereas comparable questions have been asked in studies of office environments in the United States and Canada (Marans, 1986; Sterling & Sterling, 1983).

A second advance is the use of indices to measure and identify perceptions and evaluations of an environmental attribute. For instance, a single question designed to tap peoples' rating of a particular condition may not always be interpreted correctly and consequently produce an invalid response. At the same time, a single question may not adequately measure the concept of interest. Several questions therefore are asked to cover the multidimensional aspects of environmental assessments. The responses of each individual have been combined in order to form a scale or index which more appropriately taps his/her perceptions or evaluations (e.g., Marans & Spreckelmeyer, 1983; Weideman & Anderson, 1985).

In addition to user-questionnaires and interviews as a source of quantitative data on peoples' evaluations and perceptions of an environment, ratings have been made by panels of experts (e.g., Craik & Zube, 1976). Panels have been used to judge the quality of regional landscapes, neighborhoods within communities and metropolitan areas, and workstations within office buildings. An ongoing and important line of inquiry is the extent to which the views, perceptions, and assessments of panels of design professionals correspond to those of laypersons (Lansing & Marans, 1969; Marans, 1986; Mitchell, 1971; Troy, 1971). In most cases, the research has shown little correspondence, raising questions as to the relative importance of physical environmental factors for designers and for the public.

Combining Quantitative and Qualitative Data

In addition to studies relying on quantitative data in the environment–behavior field, a number of important studies have used qualitative data in combination with quantitative techniques (see also Chap. 11 by Low). In fact, studies which base their findings on an analysis of one kind of data from a single source are increasingly viewed with suspicion and often reach fallacious conclusions. In recent years, a number of studies have appeared which use multiple sources of information including those derived from both quantitative and qualitative approaches. Some of the more noteworthy are reported in Burby and Weiss (1976), Keller (1978), and Zeisel and Griffin (1975).

Current work at the University of Michigan on lighting quality in office buildings has relied primarily on quantitative data from office workers, design experts, technicians, and indirect environmental measurement using secondary sources. Nevertheless, initial meetings with facility managers and on-site inspections of the office buildings provided additional information about the manner in which the spaces were used and how they had changed since occupancy.

DEVELOPMENTS IN DATA ANALYSIS

Methods of quantitative data analysis have blossomed in recent decades, due in large part to the proliferation of sophisticated computer software packages and the growing popularity of multivariate statistical techniques. Theoretical issues in the environment–behavior field, such as the analysis of change, causation, and multiple measures for environmental constructs can now be addressed with these techniques and available software.

Uses of Quantitative Data

As a prelude to discussing selected analytical advances in environment–behavior studies, we first review four basic uses of quantitative data in the field. These uses are the operationalization of concepts, description, examination of relationships, and predictive and causal modeling.

Operationalizing Concepts. Quite often, researchers working with concepts such as privacy, home range, visual quality, and environmental quality are faced with the task of developing appropriate measures of each and then examining them in the context of one or more environmental settings. Several measurements are taken in the belief that the data collected are direct representations of these concepts. Often, however, the researcher must sift through the data in order to understand their meaning and structure, vis-à-vis the concepts of interest. Numerous techniques are available which enable the researcher to explore systematically the structure or organization of data while at the same time, reduce the number of measures or variables into meaningful patterns. In the environment–behavior field, techniques such as factor analysis and multidimensional scaling have been used to identify and organize perceptions of environmental phenomena and attributes. Examples of these procedures can be found in Canter (1983), and Carp and Carp (1984).

Describing Environments and Users. Quantitative data can also be used to describe an environment and the people associated with the environment, including responses. Quantification of environmental conditions such as the distances between two places, energy consumption levels, or presence or absence of directional signs at key intersections in communities and in buildings can convey, along with pictures and words, the nature of an environment at a specific point in time. Similarly, quantitative data describing occupants or users of a building or other setting can enrich our understanding of the people associated with the environment and the range of activities they engage in. These descriptive data typically cover the users' age, gender, and other socioeconomic and demographic characteristics, the nature and extent of their use of an environment, and their subjective responses to the environment and of its parts. Quantitative data gathered at several points in time can enable researchers and managers to monitor systematically changes that might occur in an environment, in the people who use it, and the way they respond to it.

Examining Relationships. Early use of quantitative data in environment–behavior studies largely focused on exploring relationships between variables that measure perceptions of environments and variables that measure the characteristics of people. There is a plethora of studies showing how population subgroups feel about a particular environment or how one population reacts to alternative arrangements of the same type of environment. The extent to which associations exist is tested using various statistical techniques. There are few studies, however, which examine environmental attributes vis-à-vis peoples' responses to those attributes, although their numbers are increasing (cf. Wineman, 1986). Even fewer consider the additive and interactive effects of several environmental attributes as they relate to behavioral and attitudinal outcomes. Analytical techniques used to explore these multivariate relationships include multiple regression, dummy variable regression, multiple classification analysis, multivariate nominal scale analysis, and multiple discriminant function analysis.

Modeling. Finally, quantitative data can be used in modeling including assessing the relative importance of various independent or predictor variables in explaining key outcomes and examining causes of environmental change and behavioral phenomena. Currently, modeling is undergoing an evolution with the advent of more sophisticated techniques for exploring causation and change (Joreskog & Sorbom, 1979). Although modeling applications in the environment–behavior field are few, it is likely that the increasing availability of quantitative data, together with sophisticated analytic techniques will contribute to theoretical developments.

In the remainder of this chapter, we introduce the reader to three analytical procedures used in recent years by environment–behavior researchers, and which should contribute to further advances in the field. These procedures are: multidimensional scaling, time-series analysis, and causal or structural equation modeling.

Multidimensional Scaling

Most environment–behavior quantitative researchers have been trained in statistical methods employing the general linear model. Encountering multidimensional scaling (MDS) as a new technique is akin to listening to a chant in the Gregorian mode after continually being exposed to the chromatic mode of music. Both Gregorian and chromatic scales produce music, but have separate "rules" regarding the combination and identification of pitches. Similarly, both MDS and the general linear model attempt to analyze and understand the meaning of data, each making separate assumptions about the combination of data for analysis.

Whereas scales are the basis for understanding Gregorian and chromatic music, they also underly our understanding of these two statistical approaches. Generally, scaling is a set of rules whereby objects, behaviors, and/or attitudes are represented on a numerical scale. Until the mid-1950s this scale was typically a unidimensional, linear continuum employing interval, or equidistance units. If the researcher believed the data were not unidimensional, data items would be correlated and factor analyzed so that underlying dimensions would emerge. By the early 1960s, quantitative researchers were questioning the pervasive application of scaling techniques such as factor analysis and the applicability of linearity for several research problems (Helm, 1960). Coombs (1964) issued a challenge to researchers to begin conceptualizing data in geometric rather than linear interpretations. Such concerns underlie the development and refinement of both metric and nonmetric MDS (e.g., Kruskal, 1964).

MDS is a class of techniques which use as input data *proximities*, that is, a number indicating how similar or dissimilar two objects or stimuli are, or are perceived. The output is a spatial representation, or geometric configuration of points (each point representing an object), such as on a map or diagram, to reflect the underlying structure of the data (see example in Figure 1). The distance between points reflects the similarity or dissimilarity of objects. A major method for interpreting this spatial representation is by direct examination of the arrangement and relationship of points to each other. Systematic methods also may be used.

A common procedure for obtaining proximity data is to ask people to judge the "distance" or "similarity" of pairs of objects or other stimuli. Because an

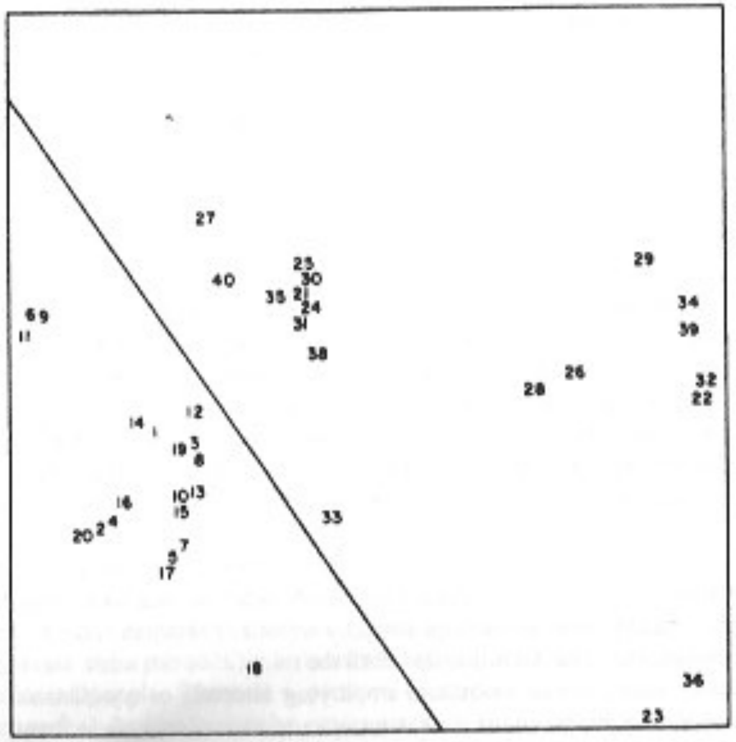

FIGURE 1. Spatial representation showing differential meaning of postmodern architecture among architects (1–20) and accountants (21–40). From "Meaning in Postmodern Architecture" by L. Groat, 1982, *Journal of Environmental Psychology, 2*(1). Copyright 1982. Reprinted by permission.

intent of MDS is to discover rather than impose dimensions, the attributes on which the objects are to be judged similar or dissimilar may not be specified for the respondents. For example, to discover the dimensions people use in conceptualizing and evaluating the external appearance of homes, Tobey (1982) presented paired drawings of 18 exterior housing facades to respondents. They were then asked to indicate on a rating scale how similar to each other the two houses in a given pair appeared to be. Ullrich and Braunstein (1975) presented respondents with pairs of different room types that might be included in a proposed classroom–laboratory complex. Respondents were then asked to indicate, using a 7-point scale, the degree of adjacency they preferred for each pair of rooms.

Another procedure for obtaining proximity data is to have respondents sort stimuli into similar groups. Respondents are asked to place stimuli into mutually exclusive and exhaustive groups so that stimuli in the same group are more

similar to each other than to those in other groups. A matrix of proximities is then derived by counting the number of times each pair of stimuli is put into the same group (Kruskal & Wish, 1978). Groat (1982) asked respondents to sort photographs of modern and postmodern buildings into piles containing buildings they felt were similar. No restrictions were made on the number of piles that could be formed or how many sorts once could do. After the sort, participants labeled the groupings and identified the constructs by which they sorted.

Profile proximity measures can also consist of correlations between variables (Wish & Carroll, 1974); these can then be regarded as proximities and analyzed by MDS (Guttman, 1966). Canter (1983) discusses two environmental studies employing this procedure, each using Likert-tye responses from questionnaires. The responses were intercorrelated and analyzed using Smallest Space Analysis (SSA).[12]

Aside from direct examination of the dimensions and the positioning of points relative to each other, more systematic means of interpreting spatial representation can be used. Several are discussed in Golledge and Rayner (1975) who compare different orientations toward assessing cognitive maps of geographic areas.

Sometimes structure can be observed not only by dimensions but also by region (i.e., bounded area; Lingoes, 1979). Canter (1983) has used this pattern approach and interpreted spatial representation by identifying hypothesized facet elements whereas Ullrich and Braunstein (1977) employed a hierarchical clustering algorithm to derive a tree diagram illustrating the desired adjancencies of rooms. These and other methods of interpretation are replete in the research literature. Nonetheless, the words of Kruskal and Wish (1978, p. 45) most accurately reflect a philosophy of interpreting MDS, "Use any means at your disposal to understand as much of the data and results as possible."

TIME-SERIES ANALYSIS

Collecting temporal data, although expanding upon the theoretical orientations and validity concerns mentioned earlier, pose special problems in data analysis. One problem is that of serial dependency: observations closer in time are more related than observations at greater time intervals. Most social data do

[12] Description of the computational procedures used among the various MDS techniques is available in Schiffman, Reynolds, and Young (1983). In essence, MDS starts with a calculation of a set of coordinates for the stimuli called the starting configuration (computation of starting configurations varies among the different computer procedures). Numerous iterations follow in adjusting the coordinates for the points until the distances best fit the data. Each program contains specific criteria for determining this final goodness of fit. These computer programs include ALSCAL, SSA, TORSCA, MDSCAL, KYST, EMD, INDSCAL.

not demonstrate serial independence. Since the assumption of independence of observations is not met, techniques such as analysis of variance (ANOVA) for time-series data are inappropriate.

Time-series analysis has come to the aid of the researcher analyzing change over time by determining the precise nature of serial dependency, and then transforming the data to remove this dependency so that subsequent statistical tests can be performed.

Time-series analysis may be of a continuous, noninterrupted nature, that is, tracking persons and/or environments over time and assessing their patterns as a whole (e.g., Brenner, 1973). Or it can focus on a single series of observations with distinct interventions, comparing trend patterns prior to and after the interruption. The former is referred to as concomitant time series, and the latter, interrupted time series.

Concomitant Time Series. By not incorporating a designated intervention point, this approach aims at assessing whether fluctuations in one series of a variable are associated with fluctuations in another variable series. Concomitant time series is quite common in economics, and is becoming more frequent in developmental psychology and policy analysis.

Several methods of concomitant time-series analysis are available, but the choice of method depends upon several considerations, especially the degree to which one wants to eliminate spuriousness. Catalano, Dooley, and Jackson (1983) present a strategy for selecting an appropriate technique, and offer examples using longitudinal data of unemployment and mental health. Cook, Dintzer, and Mark (1980) discuss procedures for conducting concomitant time-series analysis and the assumptions underlying several techniques.

Interrupted Time Series. Interest in using time data to test causality largely focuses on this approach to time-series analysis. The approach is used to describe shifts among the data points, to estimate the shift magnitude and associated level of statistical significance, and to eliminate alternative explanations for the shifts. There are several techniques for such analysis, each with its own set of assumptions about the nature of the data. The technique most frequently used in the past decade is the Auto-Regressive type and Moving Averages.

ARIMA (Auto-Regressive Integrated Moving Averages) modeling is probably the most widely used form of interrupted time series analysis (Box & Jenkins, 1970). In fact all of the major statistical analysis computer systems (BMDP, MINITAB, SAS, SPSS) include ARIMA time-series programs.[13]

Although sophisticated developments of time series analysis have boomed in the 1980s, few applications of this statistical technique exist in the environment–behavior field. Johnson, Jurik, Kreb, and Rose (1978) used time-series data to

[13]A more detailed discussion of interrupted time-series analysis is available from McCleary and Hay (1980).

evaluate the effect of engineering and policy interventions on bicycle accidents on a college campus from 1970 to 1977. The number of bicycle accidents per day was regressed on 15 predictor variables including five major engineering changes and two policy changes involving bicycle and automobile parking. Least squares estimation procedures were used to adjust for serial correlation found in the residuals of the first regression.

Typical analyses of time series data in the environment–behavior literature include ANOVA and visual assessment of time-series graphs. Although the latter can be a powerful devise to visually convey the magnitude of trend changes, both techniques are inadequate to statistically assess the impacts of change. Collecting more data points for time studies and use of statistical models assessing serial dependency are clearly needed to advance theoretical and empirical concerns of temporal change in environment–behavior relations.

Causal or Structural Equation Models

An important approach to thinking causally about the environment is through the application of structural equation models. Structural equation models, sometimes referred to as causal models, are quantitative statements showing how a change in one variable in a system affects the values of other variables in the system. In addition to their mathematical properties, causal models allow the environmental researcher to graphically develop and convey a clear statement about causal processes that are hypothesized to take place. Whereas their use may be viewed as most appropriate in the analysis of multitime data, causal models can also be used when analyzing data collected at one point in time. As with multitime data, a causal model involving one-time data must satisfy the condition of time precedence. That is, certain variables must precede other variables in time.[14] For example, Figure 2 shows that levels of office illumination precede or cause perceptions of spatial brightness and eye fatigue which, in turn, affect a person's ability to concentrate on work. The processes whereby different

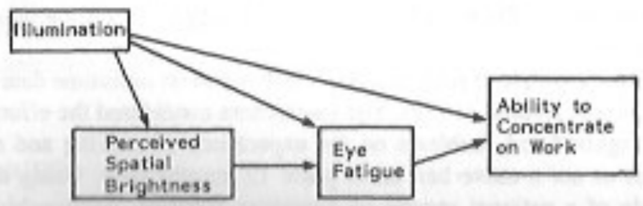

Figure 2. Hypothetical path model.

[14]Other conditions that must be met in causal modeling are covariation and nonspuriousness. These and other aspects of causal modeling are introduced in Kenny (1979).

levels of illumination cause differential perceptions and levels of concentration can be examined using various statistical techniques.

The statistical basis of structural modeling is the linear regression equation, each equation representing a directional link between variables. Structural analysis estimates the parameters in the structural regressions of the model. Multiple regression analysis, factor analysis, partial correlation, and canonical correlation can be used in structural analysis. For example, path analysis is a structural analysis where all the variables have been standardized and multiple regression is utilized.

In structural modeling each variable in the model is deemed dependent (or endogenous) or independent (or exogenous). The latter are multiplied by a structural coefficient which measures the impact of the exogenous variable on the endogenous variable. The structural equations may contain a residual or disturbance factor which represents a weighted sum of all causes of the dependent variable that the researchers did not specify. The primary statistical problem is to optimally estimate the parameters of the model and determine the goodness-of-fit of the model to data on measured variables. Bentler (1980) proposes developing competing causal models via mathematical equations and testing the models by statistical means.

Path analysis is one approach to the analysis of causality that has been used in environment–behavior research. It enables the researcher to examine the direct and indirect effects of variables considered to be causes of other variables considered to be effects. For example, Ferguson and Weisman (1986) used path analysis to explore relationships between the degree of physical enclosure of offices and employee job satisfaction and satisfaction with the workplace. Whereas the researchers' initial regression analyses of a data set showed significant relationships between openness and the two outcomes, path analyses indicated that the direct effects of openness on the two satisfaction measures were negligible and that other factors mediated the relationships. These factors include distractions due to noise and perceived privacy. The path analysis was instrumental in demonstrating the erroneous assumptions drawn from previous office research about the negative influence of open offices on employee satisfaction with their work settings.

Another example of path analysis which relied on multitime data is reported by Newman and Duncan (1979). The researchers considered the effects of housing and neighborhood problems on the expectancy of moving and eventually, on whether or not a move had taken place 12 months later. Using data from a panel study of a national sample of American families, relationships between peoples' perceptions of housing and neighborhood problems and household mobility were explored. Specifically, the relative importance of characteristics of the current environment that cause people to express residential dissatisfaction and moving intentions (Time 1 data) and to ultimately change their place of residence (Time 2 data) was examined. Among their findings, the researchers demonstrated that housing and neighborhood problems have a minimal total effect on actual mobility whereas people's evaluation of overall housing carried considerable weight in the decision to move.

IMPLICATIONS FOR THE FUTURE

In all likelihood, concerns about (a) the generalizability of research findings, (b) whether the findings can be attributable to factors other than those dealing with the physical environment, (c) the validity of instruments designed to measure constructs of interest, and (d) time perspectives will prompt more environment–behavior researchers to consider methods of inquiry that heretofore have not been widely utilized. This chapter has discussed some of these methods including innovative research designs, various approaches to data collection, and the application of multivariate statistical techniques to different analytical problems. The reader interested in learning more about these methods is encouraged to go beyond our brief presentation and examine the literature cited in our list of references.

Throughout the chapter, we have reviewed recent work in the environment–behavior field which operates under a common set of assumptions and which can be characterized as quantitative in nature. Among these assumptions is the notion that reality is something concrete, and that researchers can measure and analyse information about that reality or one's perception of it according to certain mathematical rules. The first part of our review covered developments in the design of research in the field including uses of probability sampling for selecting environments and their users. The second part expanded upon earlier methodological reviews and discussed techniques for gathering data about reality (people and their environments) and peoples' perceptions of reality. It also noted studies in the field which blend qualitative information with quantitative data collection and analysis. The final part presented an overview of the uses of quantitative data analysis and outlined three specific analysis techniques that are likely to contribute to further advancements in the field.

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