ARCHITECTURE AND TEXTILE STRUCTURES

A QUESTION OF DESIGN CHOICE

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More than 30 years of developments in textile tent and canopy structures, which were predominantly used for low-cost, temporary sheltering, have given birth to an architecture with lightweight textile structures This emerging new architecture makes conscious use of contemporary technology in materials, design and construction and has already manifested itself in a small, but noticeable number of outstanding buildings.

This paper emphasises the urgent need for environmentally sensitive building, for full integration of the appropriate building systems at the conceptual design and construction stages. It highlights the capacity of lightweight textile structures to achieve a better integration of the built and natural environments due to greater versatility and adaptability. Checklists of integrated design considerations and of parameter choices specific to lightweight architecture are given. These parameter choices are identified in a range of built examples, which are representative of current developments word-wide and their variations from building to building are shown.

ARCHITECTURE, LIGHTWEIGHT STRUCTURES, TEXTILES, DESIGN-PARAMETERS, INTEGRATION, ENVIRONMENT

INTRODUCTION

The key issue facing decision-makers universally is how to bring about the successful integration of the man-made technological environment with the natural environment of our planet Earth.

Engineers, scientists, producers and converters of materials and in particular architects, who have been traditionally responsible for the creation and realization of buildings, carry a significant responsibility towards achieving this goal.

In order to achieve a symbiosis of the two environments we must -on the one hand- expand the existing vocabulary of architectural solutions and utilise the available technological potential with new options in material, manufacture, design and construction as well as in quality control. On the other hand, however, we must scrutinize proposed solutions very carefully in order to anticipate their effect upon life in general and quality of life in particular and to ensure their compatibility and fit within the larger scale environmental context.

If architects wish to regain their leadership role in the building process and be entrusted with a major responsibility of shaping the built environment their creative design application and decision-making must be increasingly based on a holistic philosophy, namely that of response to the needs of users and occupants and those of the environment rather than to narrow satisfaction of their corporate client's short term commercial gain or of their own artistic individualism.

A morality and with it an architecture must be developed and promoted that is inherently capable to adapt to changes in life styles: an adaptable architecture which is integrated with the needs of the user/occupant and in tune with its environment similar to a tree within a forest. Adaptable, environmentally integrated buildings have been used at an elementary habitation level since mankind's early beginnings: the tents of the nomads, the yurts of Asia, the reed buildings in Iraq and the clay building settlements in Central Africa, to give some examples. Contemporary equivalents are buildings constructed from skeletal frameworks in timber or steel cladded with glass, plastics or fabrics, buildings utilising flexible tensioned cables or fabric membranes supported by slender masts, buildings employing air as the means of support and light fabric membranes enclosing large spaces.

With its roots in technology and nature lightweight architecture -including buildings with textile materials- is both a contemporary discipline and a potential tool that enables us to respond to these needs.

Lightweight construction encourages and facilitates adaptability and dynamic interaction with the natural environment.

Current knowledge derived from a track record of more than 30 years of design with lightweight textile structures, states that:

- they allow creation of complex, curved enclosures of a wide range of spans as important alternatives to established rectilinear enclosures thereby freeing the designer from the reign of cubic space

- they use new materials such as polymers and composites-industrial, coated textile fabrics, films and foils- which enable the creation of interior spaces filled with natural daylight, permitting plant growth and extensive interior landscaping thus enhancing the visual interaction of the interior space with the external environment of the building

- they allow creation of fully integrated, comfortable, economical, energy- and material- saving buildings
- they can be employed for a wide range of temporary or permanent architectural applications with particular success in assembly, exhibition, transport and storage buildings as well as for small to medium and large scale envelopes for environmental protection
- they are designed and often also manufactured with the aid of computers and require therefore a very high dimensional accuracy from other building components that interface with them
- clear spans ranging from as little as 4m to 200m and more can be covered economically.

However, lightweight fabric structures and the architecture derived from them should not be seen as a panacea for the current dilemma in architecture, but rather as an alternative to conventional buildings and construction methods, a possibility to be explored and selectively applied in a rational, unbiased and professional manner along with established techniques.

DESIGN WITH TEXTILE STRUCTURES

Textile materials

Three principal types of coated textile fabrics are used:
PVC-coated polyester fabrics with or without surface film laminates,
PTFE-coated glass fibre fabrics and Silicone-coated glass fibre fabrics.
Each material type has particular characteristics that affect it's suitability for a particular building application.

PVC-PES was initially developed for temporary air- and prestressed tent structures during the 1950's and 1960's and has a typical service life from between 10 to 20 years depending on use and surface treatment. The material is the most versatile of the three, low-cost, easily worked and tailored to the application: performance characteristics such as translucency, colour, resistance against UV-degradation, flame propagation and fungal growth can be varied through adding various chemical additives to the coating.

PTFE-Glass was developed during the late 1960's and early 1970's in response to the need for a more durable, dimensionally stable, chemically inert membrane fabric for use in permanent buildings requiring normal fire ratings. PTFE has excellent self-cleaning characteristics and maintains its white surface colour although it may support fungal growth. Material and conversion costs are significantly higher than for PVC-PES. Estimated life spans range from 20 to 30 years and more.

Silicone-Glass has been developed relatively recently (during the 1980's) with properties between the other two materials although significantly higher translucencies (up to 50%) can be obtained. It can be coloured, displays better flame retardent properties than PVC-PES and allows transmission of watervapour, making it particularily suitable for interior applications such as internal layers, ceilings and light fittings.

Other materials include PVA-coated PES or PTFE-coated Kevlar fabrics as well as other materials developed for special applications.

Coated fabrics are used for three principal applications:

- -non-structural (roof and wall cladding or for interior design)
- -semi-structural (supported by cables or ribs, nets or grids)
- -structural (either as prestressed or non-prestressed load-bearing secondary support surfaces such as tent and air-structures)

Designing by integration

The designer of lightweight structures must be conscious of the materials involved in lightweight construction and exploits the potential of structural form, not only as a guarantee for a safe structure but also for constructional economy and. more significantly, as a powerful means of architectural expression and integrity of design.

Structure, envelope and interior are inseparable and introduce therefore a degree of restraint which demands a different design approach.

Architectural aspects must be considered simultaneously with structure, material, construction/assembly, safety and economy (see Table 1) and a high level of integration of building systems is required.

TABLE 1: DESIGN BY INTEGRATION

Architecture (conceptual establishment of the building volume and it's context)

external environment

- **siting/environmental fit**
- external appearance
- building volume

internal environment

- space
- function
- comfort
- appearance

Structure (the support system for the building volume)

primary

- **system**
- **shape**

secondary

- **system**
- **shape**

Material (the materials constituing the support system and the envelope of the building volume)

primary

secondary

- **structural membrane**

tertiary

- **cladding membrane**

Construction/Assembly (components and processes for establishing support system and envelope of the building volume)
footings/anchorages
primary support structure
prefabricated
in-situ
membrane
pre-shaped prefabricated surface
in-situ
fitting-out
installation
services
finishes (cladding)

Safety (safe occupancy of the building volume)
fire
vandalism
structural failure

Economy (establishment and running costs for the building volume)
establishment cost
quality control
design
materials
fabrication
assembly
in-use
life-cycle cost
life-cycle performance
maintenance/upkeep

Successful design in lightweight architecture depends on the knowledge of those parameters and physical laws which govern the intricate relationships between structure, shape, material and architectural expression. The three-dimensional model is the central medium for conceptual design. The design process cannot be separated into its architectural, engineering, environmental and constructional parts, and considerable skill, advanced technological know-how and a highly developed capacity for teamwork, communication and competence of all the players in the team are needed in order to achieve the harmonious integration between these essential parts. Engineering requirements-structural behaviour and load-bearing capacity- and architectural requirements-aesthetics and function- are both dependent on the shape of the building thereby rendering the conceptual process of formfinding the key to the successful integration between architectural and structural design.

Lightweight fabric structures utilise industrialised methods of construction through systemised component manufacture and assembly, and normally require only minimal amounts of material per unit of covered area.

While technological progress has been considerable and a large number of buildings have been constructed world-wide, the achievements are predominantly of a technological kind. Todate only a relatively small number of successfully integrated buildings has been constructed. Examples are: Diplomatic Club Riyad (Frei Otto and OMRANIA), the Stephen O'Connell Centre at Gainsville, Schlumberger Headquarters Montrouge (Renzo Piano).

Architectural designers at large are only beginning to respond to the challenge which is offered through the rich formal and structural variety found in fabric structures and have not yet utilised the potential of this new medium on a significant scale. In order to realize this potential and to achieve this integration, architects must cooperate much closer with other specialists on the design and implementation of lightweight structures than is practised in contemporary building.

This cooperation must be based on better mutual understanding of technological and environmental issues and requires a mutual information, learning and communication process for all specialists involved in the design and construction process of the building.

Most successful textile buildings were designed by specialist teams involving architects, engineers (structural, mechanical, lighting, acoustical, energy consultants) and fabricator/contractors.

The range of parameters affecting design integration is listed giving the basic choices available to the designer (see Table 2)

TABLE 2: PARAMETER CHOICES FOR DESIGN INTEGRATION

Types of textile structures:

(according to degree of structural use of the textile material)

Structural:
air-structures
tents

Semi-structural:
supported from grid, net, rib or cable structures
interior design applications

Non-structural:
cladding of roofs/walls
interior design applications

Types of architectural applications:

Primary types:
as a stand-alone
as a component:
(i.e. integrated with conventional construction)

Secondary types:
as a complete building
as a building component:

- **roof**
- **wall**
- **other(e.g. ceiling)**

as an enclosure
stationary
movable
as a canopy
stationary
movable
Tertiary types:
environmental protection
outdoor stages
indoor sports and multi-purpose facilities
assembly facilities
exhibition facilities
commercial outlets
feature structures
interior design
other

Types of building volume shape (architectural/structural):
(refer to the types of textile structures above)

For structural types:
air-structures:
air-supported:
sphere-dome
cylinder-vault
cone
air-inflated:
all of the above
prism-polyhedron
pyramid
tent structures:
prestressed:
saddle-cone
saddle-pyramid
saddle-prism
saddle-polyhedron
saddle-cylinder
saddle-vault
saddle-dome
For semi-structural types
the full range of building volume shapes depending on support structure
For non-structural types:
the full range of building volume shapes depending on support structure

Types of building volume shape:
Unit
Aggregate

Variants of envelope properties :
(choice of shape/material/construction for comfort appearance and ambience in response to:)

Comfort:

Light:
transparent
translucent
opaque

Heat:
reflector
transmittor
absorber (insulation-ventilation)
collector (greenhouse)

Sound:
transmittor
absorber
disperser
focusser

Appearance:
external surface
internal surface
proportion
colour

Ambience:

ARCHITECTURE WITH TEXTILE STRUCTURES A SELECTION OF EXECUTED EXAMPLES

26 projects were selected as being representative of the state of the art in contemporary architecture with textile structures. The projects are both, systematically listed in form of a database (see Tables 3/1 and 3/2) and selectively illustrated (see Figures 01-19: project numbers correspond to numbers in tables). Choices affecting design integration are identified under the following parameter categories: structure type, application type, building volume shape, material type, building volume type as well as characteristics of the envelope in terms of light, heat, sound and internal appearance.

The selection has been sorted in preferences of:

structure type (textile material used non-structurally, semi-structurally or structurally),
application type I (the textile structure being stand-alone or component of a larger building or complex) and
application type II (the textile structure being a complete building, a component of a building such as a roof, ceiling or wall structure, an enclosure or a canopy)

TABLE 3/1 EXAMPLES OF EXECUTED STRUCTURES

PROJECT NAME / Project/Illustration Number	COUNTRY / MATERIAL	YEAR / TYPE	STRUCT TYPE / BUILD VOL TYPE	APPLIC TYPE I / ENVELOPE:LIGHT	APPLIC TYPE II / ENVELOPE:HEAT	APPLIC TYPE III / ENVELOPE:SOUND	BUILDING VOLUME SHAPE / ENVELOPE:INTERNAL
Wilkhan Pavilions Bad Münder	Germany	1987	***non-struct:clad***	*integrated*	*building component:*	commercial:exhibition	saddle-cone
PROJ 01	PVC/PE		aggregate	opaque	absorber	absorber/disperser	enclosure:uplifting
Baths Bad Dürrheim	Germany	1987	***non-struct:clad***	*stand-alone*	*building*	indoor sports	saddle-cone
PROJ 02	PVC/PES		aggregate	opaque	absorber	absorber/disperser	enclosure:uplifting
Tacoma Dome	USA	1983	***non-struct:clad***	*stand-alone*	*building*	multipurpose	dome
PROJ 03	PVC/PES		unit	opaque	absorber	absorber/focusser	enclosure:heavy
Offices Bradford Exchange	USA	1985	***non-struct:tent***	*integrated*	*building*	commercial:offices	saddle-cone
PROJ 04	Silicone/Glass		aggregate	reflector	transmittor	transmittor/disperser	envelope:uplifting
Alexandra Palace London	England	1988	***non-struct:tent***	*integrated*	*component:ceiling*	exhibition	saddle-vault
PROJ 05	Silicone/Glass		aggregate	reflector	reflector	reflector/disperser	envelope:uplifting
Showroom Light Fitting	USA	1987	***non-struct:tent***	*integrated*	*other*	other:lightfitting	
PROJ 06	Stretch Fabric		unit/aggregate	translucent	n/a	n/a	sky-light artificial
Staff House Woodlands School	England	1987	***semi-struct:grid***	*integrated*	*building*	assembly facility	saddle-prism
PROJ 07	PVC/PES		unit	opaque	absorber	absorber/disperser	enclosure:heavy
Diplomatic Club Riyadh	Saudi Arabia	1985	***semi-struct:tent/net***	*integrated*	*building*	assembly facility	saddle-cone
PROJ 08	PTFE/Glass		unit	translucent	reflector/absorber	transmittor/disperser	sky-light
Nuage Grande Arche La Defence	France	1989	***semi-struct:tent/net***	*integrated*	*canopy:stationary*	feature	saddle-surface
PROJ 09	PTFE/Glass		unit	translucent	transmittor	transmittor/disperser	umbrella:floating
Stephen O'Connell Center	USA	1981	***struct:air-str/tent***	*stand-alone*	*building*	indoor	prism:dome-top
PROJ 10	PTFE/Glass		unit	translucent	reflector/transmittor	transmittor/focusser	sky-light
Arena Nimes	France	1988	***struct:air-structure***	*integrated*	*roof*	env.protection:assem	cylinder:dome-top
PROJ 11	PVC/PES		unit	translucent	reflector/absorber	transmitter/disperser	umbrella:heavy
Technocosmos Pavilion Tsukuba	Japan	1985	***struct:air-structure***	*stand-alone*	*building*	exhibition	vault
PROJ 12	PVC/PES		unit/aggregate	opaque	reflector/absorber	transmittor/focusser	enclosure:heavy
Pavilion Motor Inn Canberra	Australia	1988	***struct:tent***	*integrated*	*building component*	assembly facility	saddle cone
PROJ 13	PTFE/Glass		aggregate	translucent	reflector/collector	transmitter/disperser	sky-light

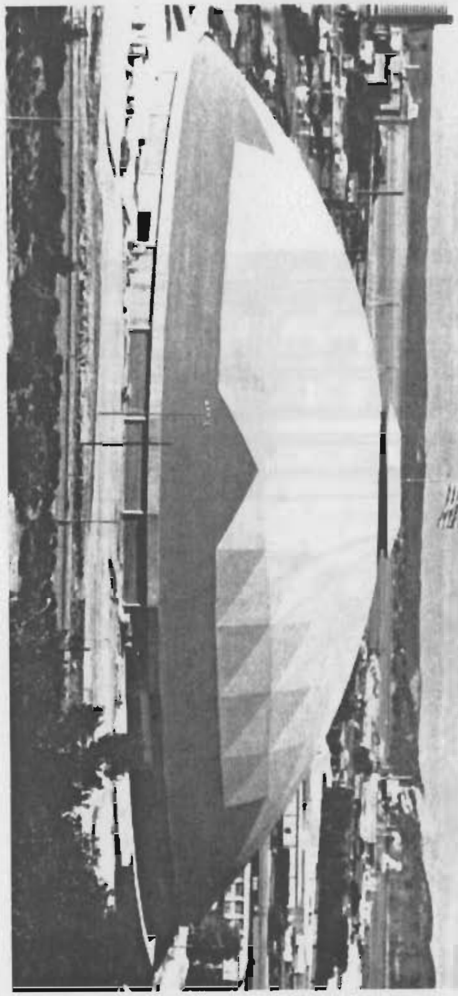

FIG.03 PROJ.No. 03

FIG. 02 PROJ.No. 02

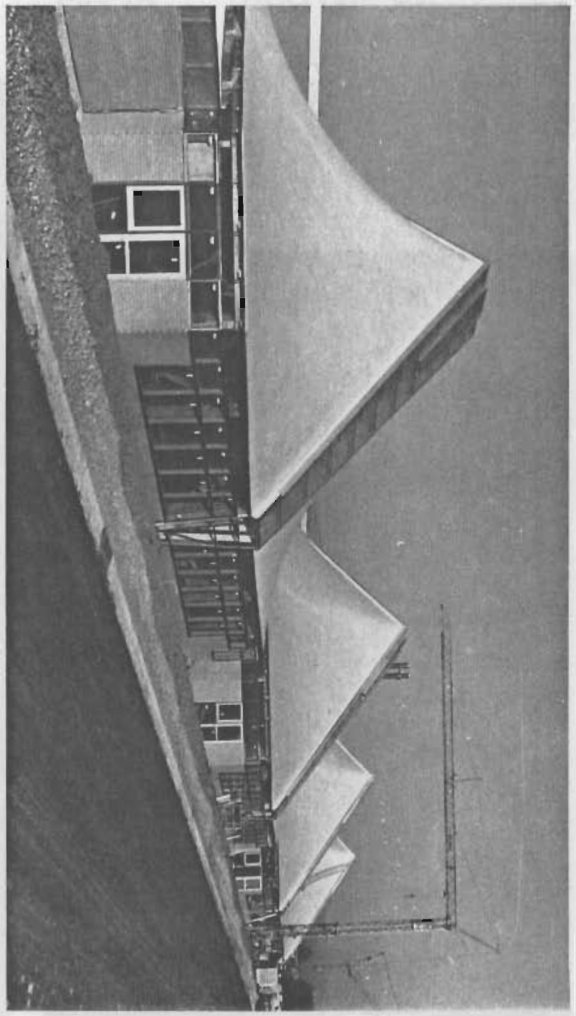

FIG. 01 PROJ.No. 01

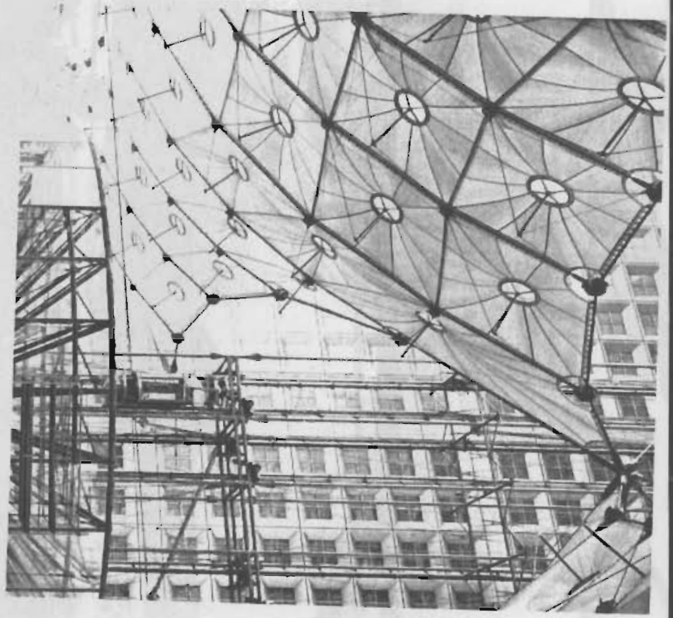

FIG. 05 PROJ.No. 09

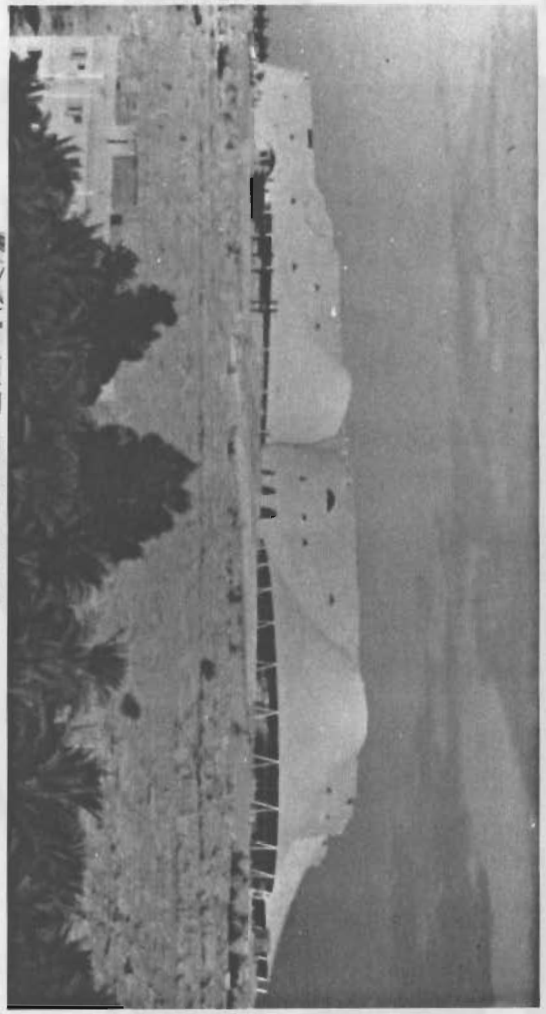

FIG. 04 PROJ.No. 08

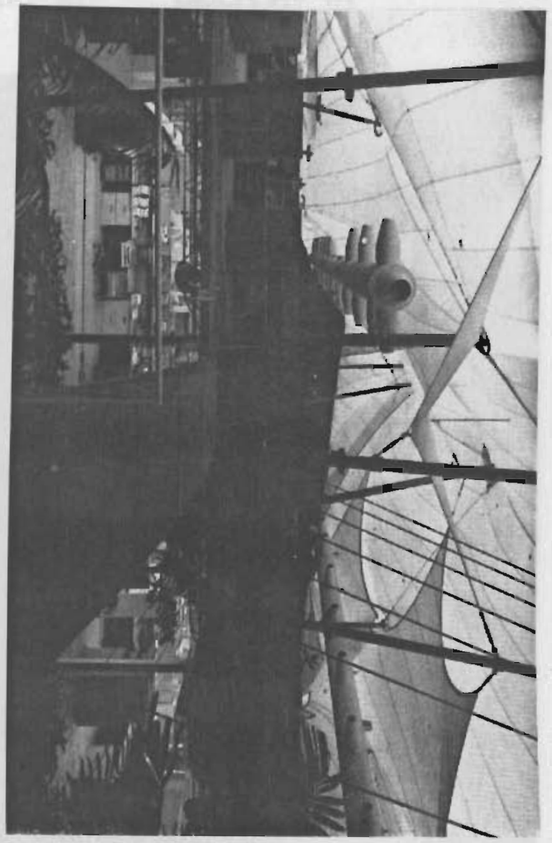

FIG. 04 PROJ.No. 04

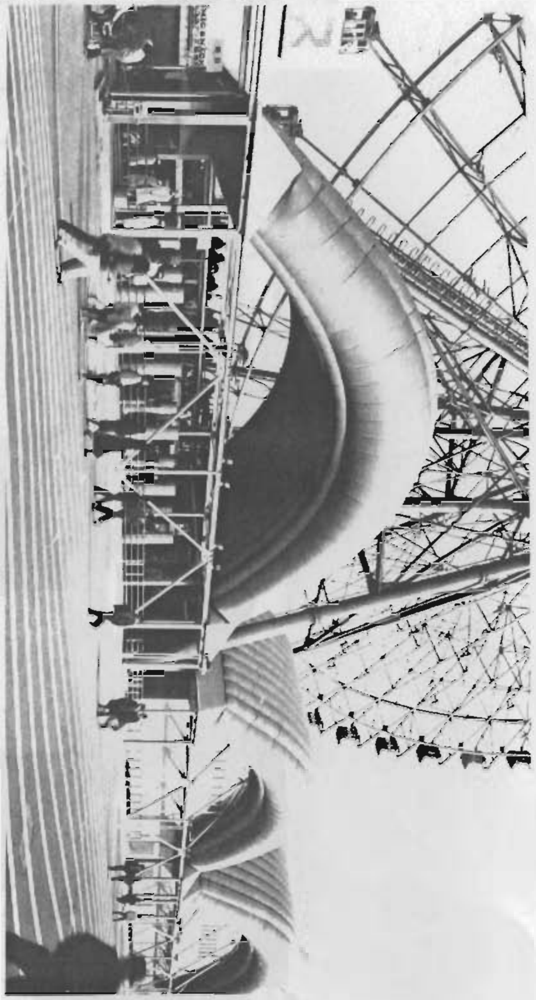

FIG. 08 PROJ.No. 12

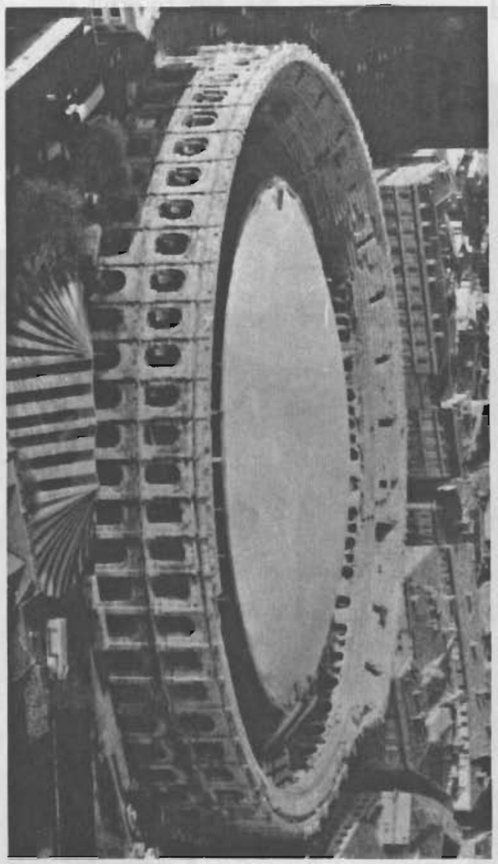

FIG. 07 PROJ.No. 11

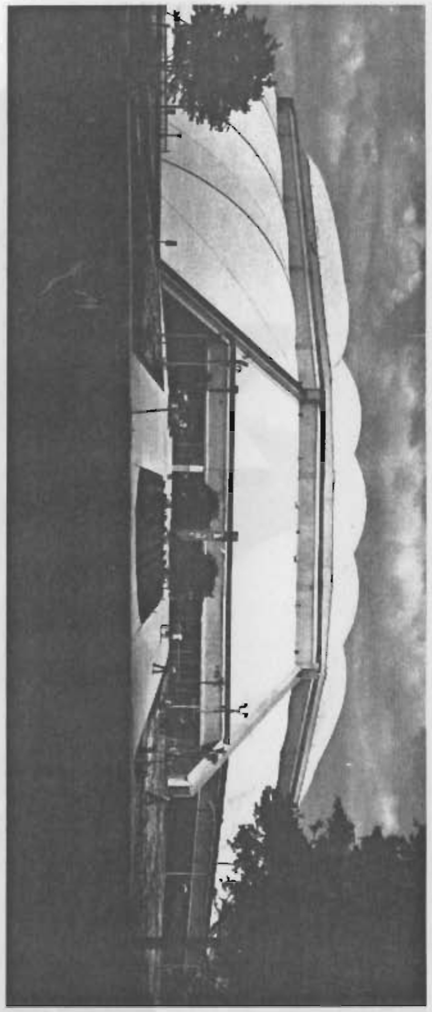

FIG. 06 PROJ.No. 10

FIG. 11 PROJ.No. 15

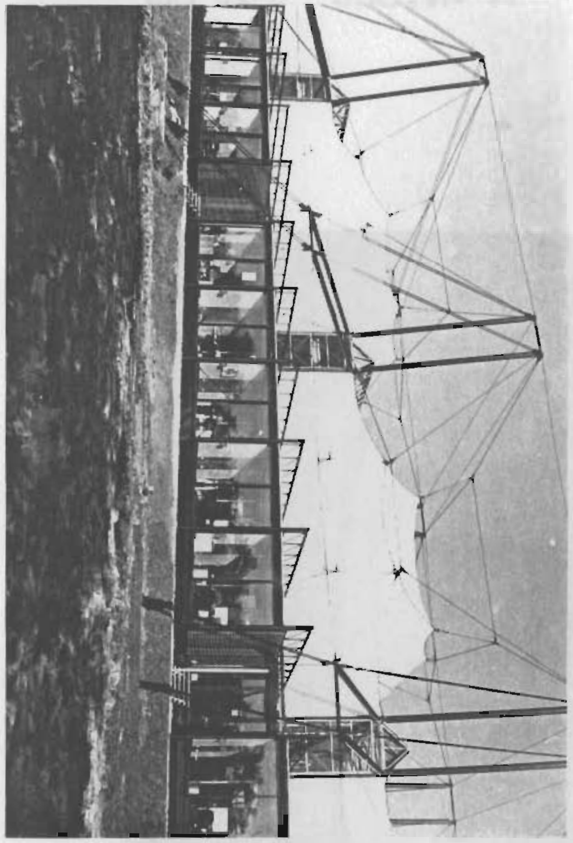

FIG. 10 PROJ.No. 14

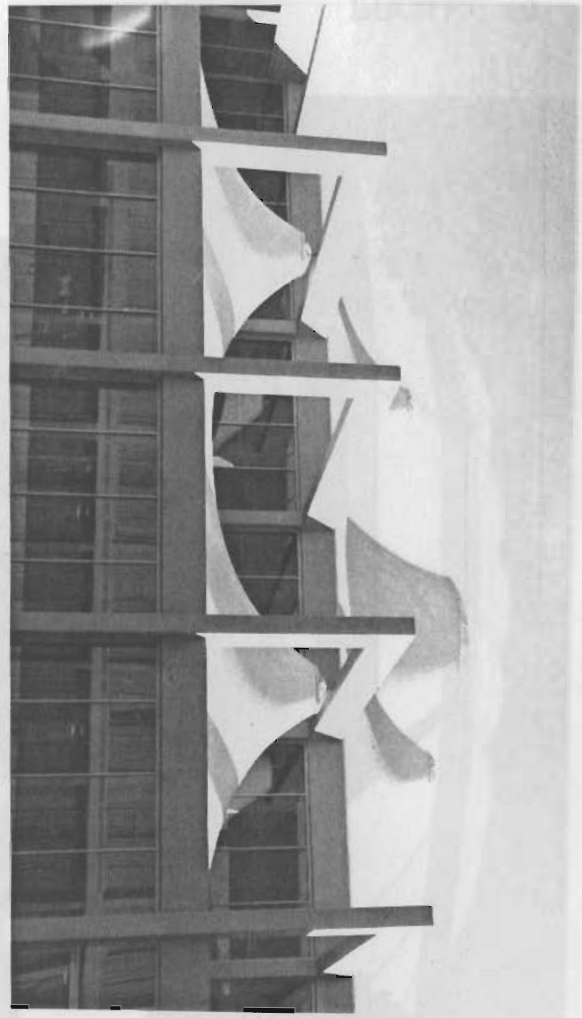

FIG. 09 PROJ.No. 13

TABLE 3/2 EXAMPLES OF EXECUTED STRUCTURES

PROJECT NAME / Project/Illustration Number	COUNTRY / MATERIAL TYPE	YEAR	STRUCT TYPE / BUILD VOL TYPE	APPLIC TYPE I / ENVELOPE:LIGHT	APPLIC TYPE II / ENVELOPE:HEAT	APPLIC TYPE III / ENVELOPE:SOUND	BUILDING VOLUME SHAPE / ENVELOPE:INTERNAL
Research Laboratory Cambridge	England	1984	***struct:tent***	*integrated*	*building*	other:industrial	saddle-prism
PROJ 14	PTFE/Glass		aggregate	translucent	transmittor	transmittor/disperser	sky-light
Schlumberger Montrouge	France	1985	***struct:tent***	*integrated*	*canopy:stationary*	assembly/env.protecti	saddle-cone
PROJ 15	PTFE/Glass		aggregate	translucent	reflector/transmittor	transmitter/disperser	umbrella:floating
Chadstone Rotunda	Australia	1984	***struct:tent***	*integrated*	*component*	commercial:retail	saddle-dome
PROJ 16	PTFE/Glass		unit	translucent	reflector/transmittor	transmitter/focusser	sky-light
Penguin Parade	Australia	1987	***struct:tent***	*integrated*	*component*	feature/env.protection	saddle-cone
PROJ 17	PVC/PE		aggregate	translucent	reflector/transmittor	transmittor/disperser	enclosure:uplifting
Le Zenith Parc la Vilette	France	1984	***struct:tent***	*stand-alone*	*building*	multipurpose	prism
PROJ 18	PVC/PES		aggregate	opaque	reflector/absorber	transmittor/disperser	enclosure:heavy
Gymnastics Stadium Seoul	Korea	1986	***struct:tent***	*stand-alone*	*building*	indoor sports	cylinder saddle-dome-top
PROJ 19	Silicone/Glass		unit	translucent	reflector/transmittor	transmittor/focusser	sky-light
Stadium Riyadh	Saudi Arabia	1986	***struct:tent***	*stand-alone*	*canopy:roof/wall*	env.protection:grandst	saddle-pyramid
PROJ 20	PTFE/Glass		aggregate	translucent	reflector/transmittor	transmittor/disperser	umbrella
Stage 88 Canberra	Australia	1988	***struct:tent***	*stand-alone*	*canopy:stationary*	outdoor stage	saddle-vault
PROJ 21	PVC/PE		unit	translucent	reflector/transmittor	transmitter/disperser	umbrella
Lloyd Rees Bandstand	Australia	1982	***struct:tent***	*stand-alone*	*canopy:stationary*	outdoor stage	saddle-dome
PROJ 22	PVC/PE		unit	translucent	reflector/transmittor	transmittor/focusser	umbrella
Storage Halls Roissy-Charles de	France	1989	***struct:tent***	*stand-alone*	*canopy:stationary*	env.protection:storage	saddle-vault
PROJ 23	PVC/PES		aggregate	translucent	reflector/transmitter	transmitter/disperser	umbrella
Shipstation/Walkway WT Center	USA	1988	***struct:tent***	*stand-alone*	*canopy:stationary*	env.protection:termina	saddle-vault
PROJ 24	PVC/PES		aggregate	translucent	reflector/transmittor	transmittor	umbrella
Hajj Terminal Jeddah	Saudi Arabia	1981	***struct:tent***	*stand-alone*	*canopy:stationary*	env.protection:termina	saddle-cone
PROJ 25	PTFE/Glass		aggregate	translucent	reflector/transmittor	transmittor/disperser	umbrella
Solar Oasis Tucson	USA	1985	***struct:tent/air-structu***	*integrated*	*building*	env.protection:filter	saddle-prism
PROJ 26	Silicone/Glass		unit	translucent selective	reflector/transmittor	transmittor/disperser	envelope:light

FIG. 14 PROJ.No. 19

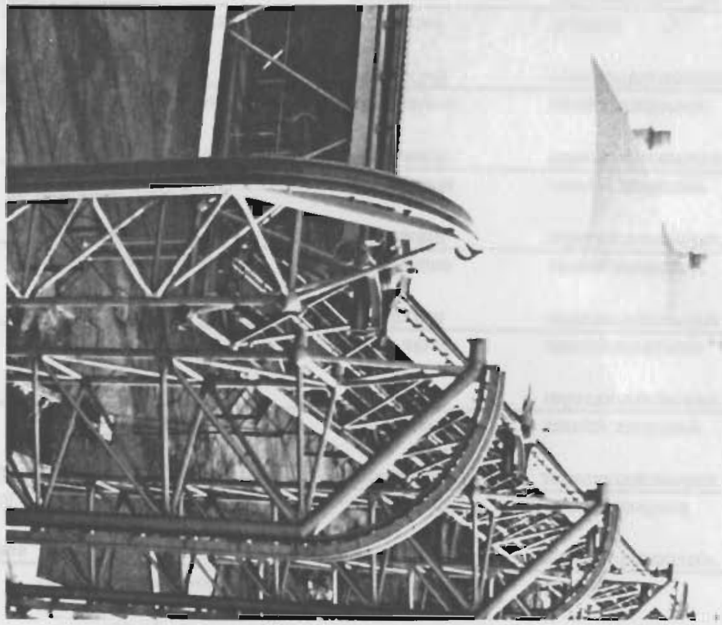

FIG. 13 PROJ.No. 18

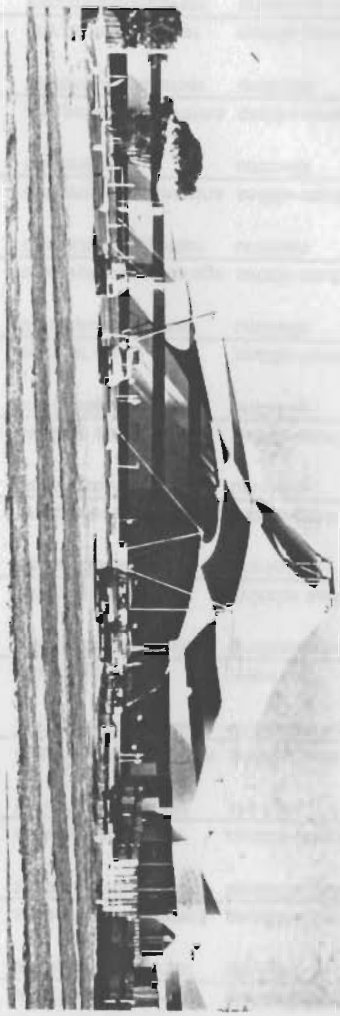

FIG. 12 PROJ.No. 17

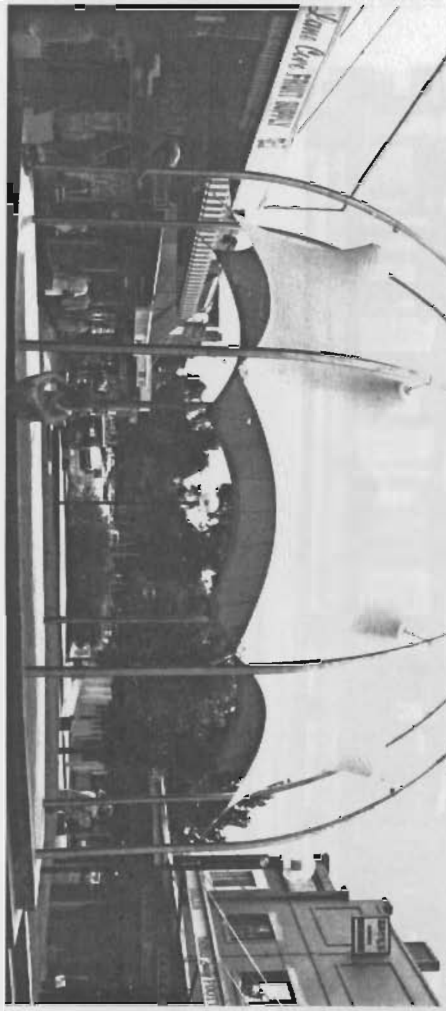

FIG. 17 PROJ.No. 22

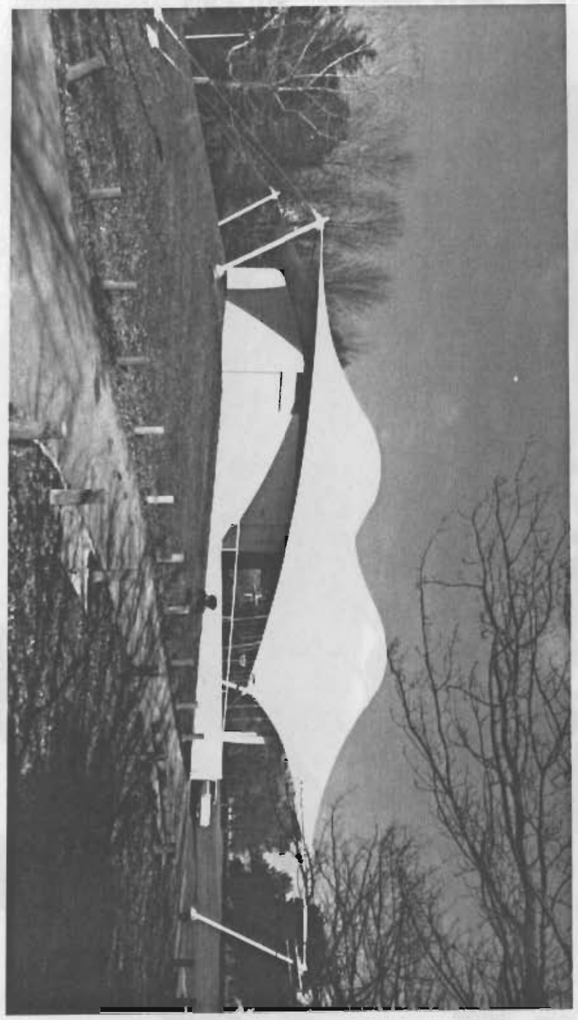

FIG. 16 PROJ.No. 21

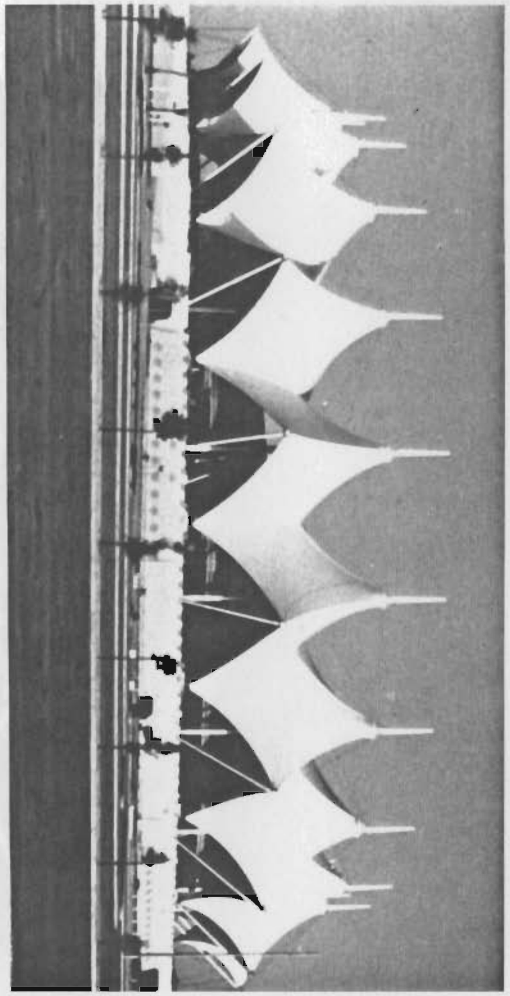

FIG. 15 PROJ.No. 20

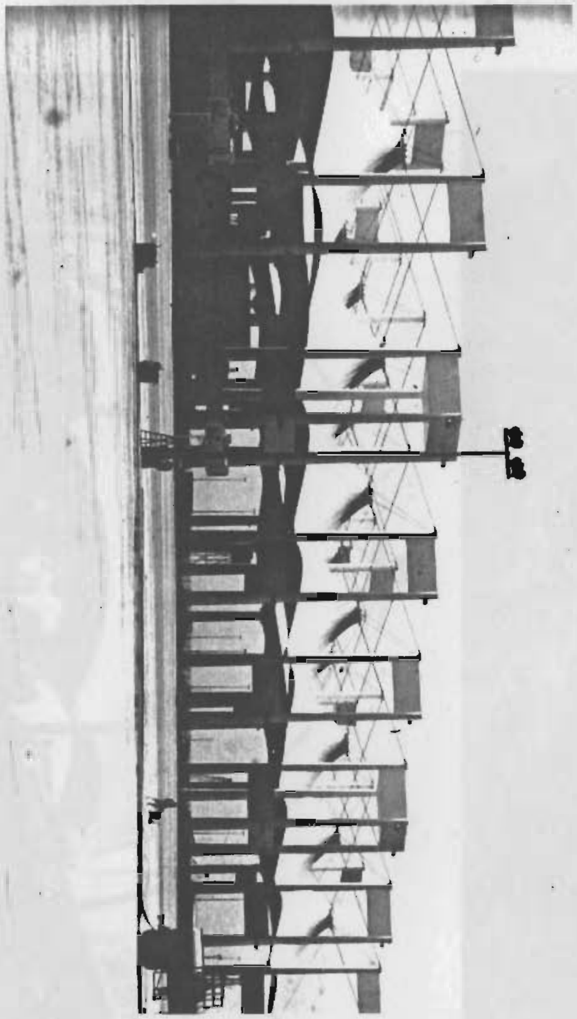

FIG. 19 PROJ.No. 25

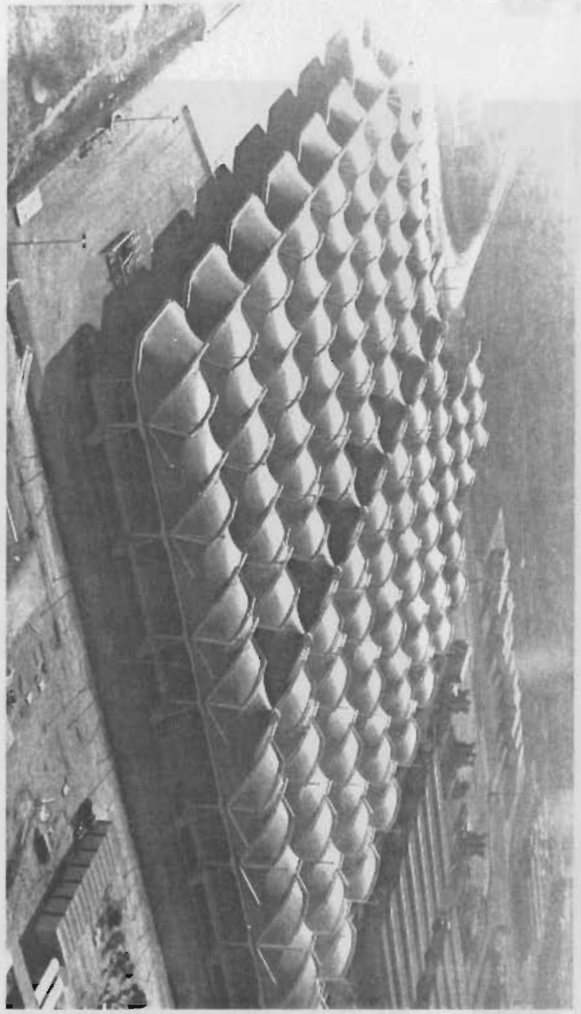

FIG. 18 PROJ.No. 23

CONCLUSION

Fabric structures are being utilized at an increasing rate by architects throughout the world seeking a contemporary adaptable medium of architectural expression based on current technology and materials.

Consideration of the building as a completely integrated package in terms of design-construction-erection-maintenance-economy coupled with satisfactory internal and external environmental conditions has emerged as the one and only successful approach to building.

In order to achieve a satisfactory integration of our man-made world with nature, we must expand the existing vocabulary in building, fully understand and utilise the technological capacity available to us under close scrutiny for any implications of this technology for life and the quality of life. We must aim at the creation of the integrated whole environment where physical and non-physical aspects are considered with equal emphasis.

Integration of the man-made and natural environments can be achieved and, when implemented will lead to vastly improved relationship between man and his original background and subsequently to improvements in his physical and psychological well-being.

An architecture with lightweight structures has the capacity to contribute to much needed improvements in our built environment.

Finally, the acceptance of lightweight textile fabric structures by occupants, clients, architects and by the general public at large will largely depend upon their integration into mainstream architecture, the success and of constructed buildings, their economy, and on the degree of satisfaction people experience during occupancy.

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