DESIGN and DETAILING of PERFORATED BRICK SCREEN WALLS

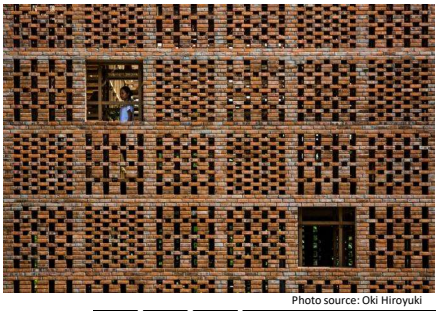


Photo source: Oki Hiroyuki

October 15, 2020

Brian E. Trimble, PE, LEED AP
Director, Industry Development and Technical Services
International Masonry Institute

THE MASONRY SOCIETY

1

CONTINUING EDUCATION AIA

The Masonry Society is a registered Provider with the American Institute of Architects Continuing Education Systems. Credit earned on completion of this program will be reported to CES Records for AIA members. Certificates of completion for non-AIA members are available upon request.

This program is registered with AIA/CES for continuing professional education. As such, it does not include content that may be deemed or construed to be an approval or endorsement by the AIA of any material of construction or any method or manner of handling, using, distributing or dealing in any material or product.

Questions related to specific materials, methods, and services will be addressed at the conclusion of this presentation.

The Masonry Society

AIA Provider: 50119857

AIA Course Number:

2

2

Course Description

Architects are using brick in unique ways as a material of choice and have experimented with incorporating voids in the cladding. Brick screen walls have been used in residential applications for decades to screen undesirable elements such as trash and HVAC equipment. In fact, perforated walls were common in Persia dating back centuries. Now, architects are using screen walls for the entire façade of a structure. With this increased usage is an increased desire to have rules on how to design these elements.

3

Learning Objectives

- Attendees will be able to determine if perforated brick screen walls can be used on their projects.
- Attendees will learn what some of the limits are for using these walls in the building envelope.
- Attendees will be able to detail perforated brick screen walls to deal with moisture issues and expansion and contraction.
- Attendees will learn about projects from around the world and how they approached the design of perforated walls.

4

Outline

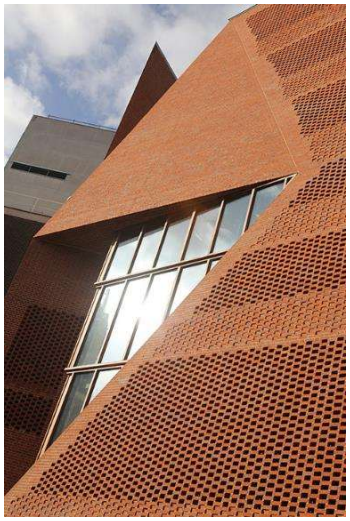
- History and Past Usage of Perforated Screen Walls
- Structural Design of Perforated Screen Walls
- Detailing of Perforated Screen Walls
- Case Studies of Perforated Screen Walls in the Façade of Buildings
- Further Research and Conclusions

- Information on Obtaining Certificates of Attendance/ AIA LUs

5

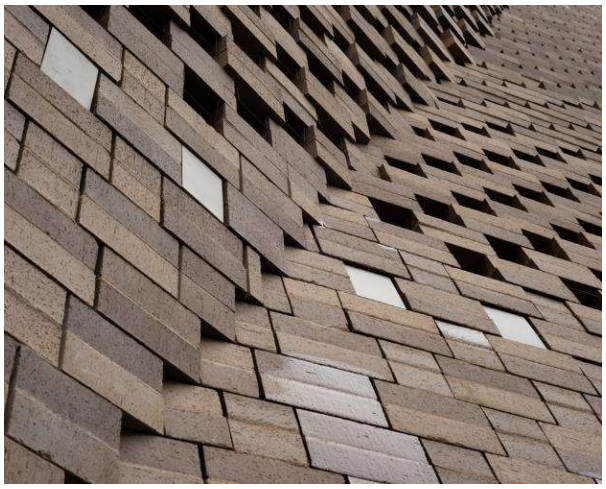
6

Let's Try Something Different



Photos source Dezeen.com

Saw Swee Hock
Student Center, London

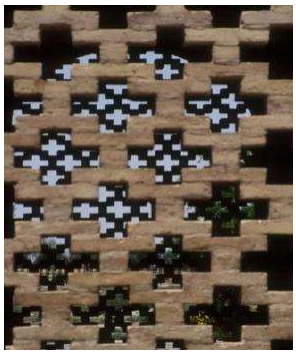


Switch House Tate Museum, London

7

Perforated Screen Walls

- Helps diffuse natural daylight, while providing shade and illumination to indoor spaces
  - Persian screens are some of the earliest examples



8

Perforated Screen Walls

- Reduce solar gain while allowing air movement

South Asian Human Rights Documentation Centre, New Dehli, India

Photos source Dezeen.com

Masdar City, Abu Dhabi

Perforated Screen Walls

- Used to provide privacy without totally blocking views

Perforated Screen Walls

- Architectural feature

West Village Building

HS Residence, Cleveland, OH

Photos source: Dezeen.com and Christian Phillips

11

Perforated Screen Walls

- Architectural feature

Photos source Dezeen.com

LaStella Residence, Locarno, Switzerland

12

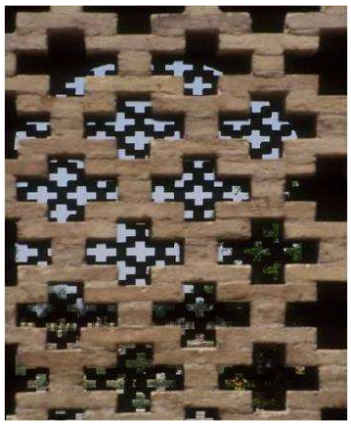
Perforated Screen Walls

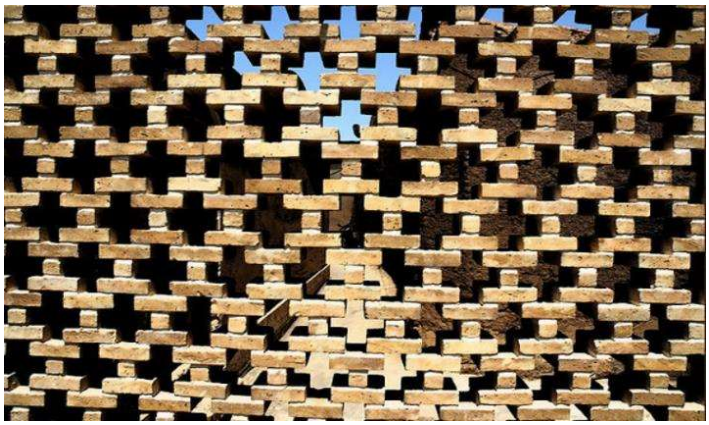
- Also known as:
  - Screen walls
  - Pierced walls
  - Lattice walls
  - Hit and miss brickwork
  - Jali
- Similar, but not the same
  - Brise soliel (sunscreen, usually horizontal)
  - Mashrabiyas (projecting window with a wooden screen)

13

History of Perforated Screen Walls

- Used extensively throughout Persia and Middle East as indigenous architecture

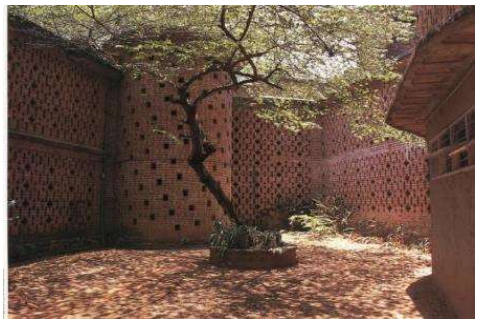




14

History of Perforated Screen Walls

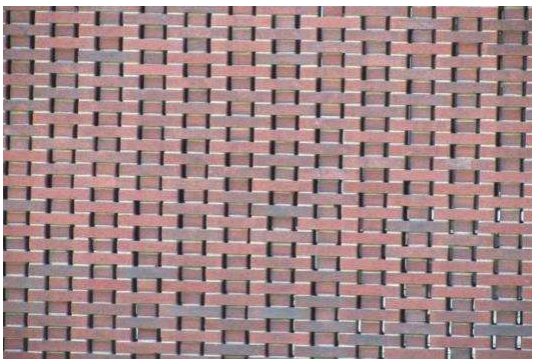
- Laurie Baker designed an extensive array of perforated walls in India

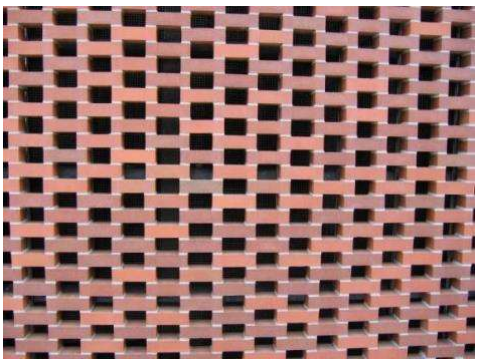


15

What Constitutes a Perforated Screen Wall

- Percentage of open area can vary between 5% to 51% (or more) depending on size of the unit and opening
- Larger openings result in weaker wall





16

What Constitutes a Perforated Screen Wall

- Wall is usually a single wythe of brick and may or may not have wall/support behind it (often glass)

Weave House, Chicago, IL

Beechview Library, Pittsburgh, PA

Photos source: Studio Gang and GBBN Architects

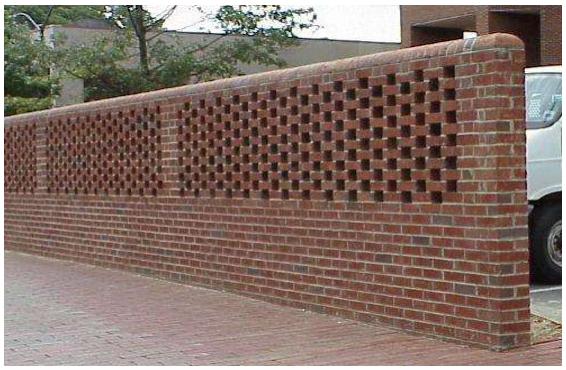
17

Structural Design of Perforated Screen Walls

18

Structural Design of Perforated Screen Walls

- Area of perforated brickwork has been typically small
- Distance between “supports” has typically been based on engineering judgment



Photos source: Dezeen.com

19

Research on Perforated Screen Walls

- Limited research on structural capacity of perforated screen walls
- Research and resulting papers include:
  - Ortlepp & Schmidt, “Perforated Masonry – light weight construction”, 9th International Masonry Conference, 2014
  - Masia et al, “Flexural Strength of Unreinforced Lattice Masonry Walls Subjected to Out-of-plane Loading”, 13th Canadian Masonry Symposium, 2017
  - Masia et al, “Experimental testing of unreinforced lattice masonry walls subjected to out-of-plane pressure loading”, 17th International Brick and Block Masonry Conference, 2020

20

Ortlepp, Technical Univ. of Dresden

- Goals:
  - Determine the loadbearing capacity of perforated screen walls

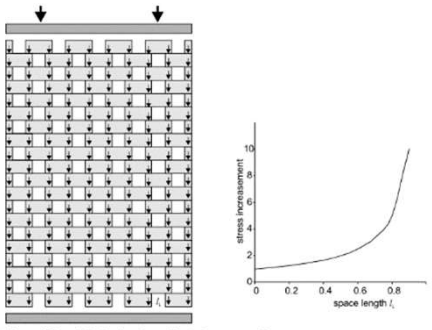


Figure 12. Load distribution of a perforated masonry wall

9th International Masonry Conference 2014 in Guimarães

Perforated masonry – light weight construction

ORTLEPP, SEBASTIAN[1]; SCHMIDT, FALCO[2]

ABSTRACT:

Perforated Masonry has high permeability to air, noise, heat and light. Due to this fact, particular applications are favoured. Thereby result favourites for its applications. Even in projects with limited resources, the use of a light and air permeable structure is recommended because this type of construction is efficient, quick and easy realizable. This separate casting wall shows in unheated rooms its particular advantages of special light effects. A starting research project at the Technical University of Dresden deals with the behavior of lightweight construction for publishing new results for the load bearing capacity.

Keywords: Perforated masonry, load bearing element

NOTATION

A_w cross section;
V volume
V_E volume of the Unit
V_L volume of the hole
m mass
m_S mass of the unit
m_L mass of the hole = 0
ρ_{Mw} global density
ρ_S density of the unit
l_E unit length
l_L space length
p_L space ratio
p_{KI} contact ratio
g dead load of the wall

1 INTRODUCTION

Perforated masonry is defined by a regular solid brick wall, in which the gaps between two adjacent units are either openings or filled with non-load bearing material. The construction without fillings is characterized by transmission of air, noise, light and heat. An important factor for the of the definition of perforated masonry is the size of the gaps, which can not be used to pass-through the wall.

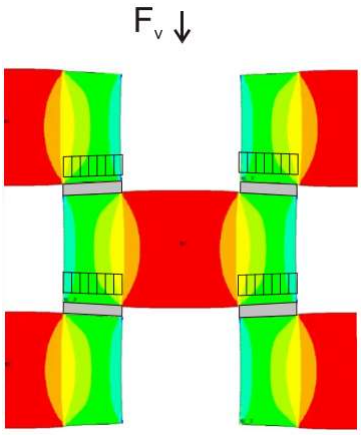
In addition to this subject there is a small kind of camouflage. A particular need for visual protection exists not only for the private sector to keep the personal sphere, but also for the public domain. It is

Ortlepp, Technical Univ. of Dresden

- 3 comp strength tests with spacing ratio = 0.5
- 1 shear test with spacing ratio = 0.35

Ortlepp, Technical Univ. of Dresden

- Compressive behavior



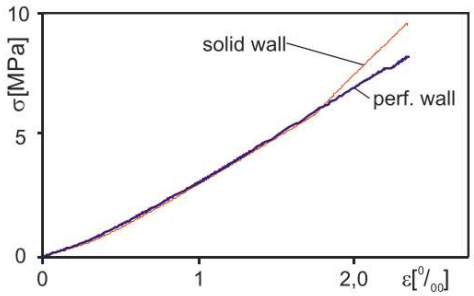


Figure 12. Test setup for compressive strength of perforated specimen

Ortlepp, Technical Univ. of Dresden

- Shear behavior

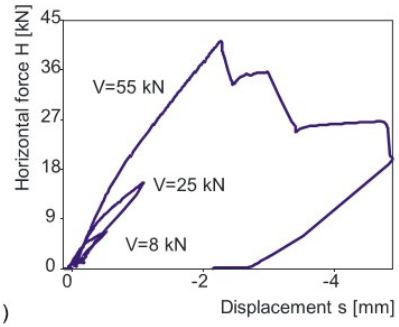
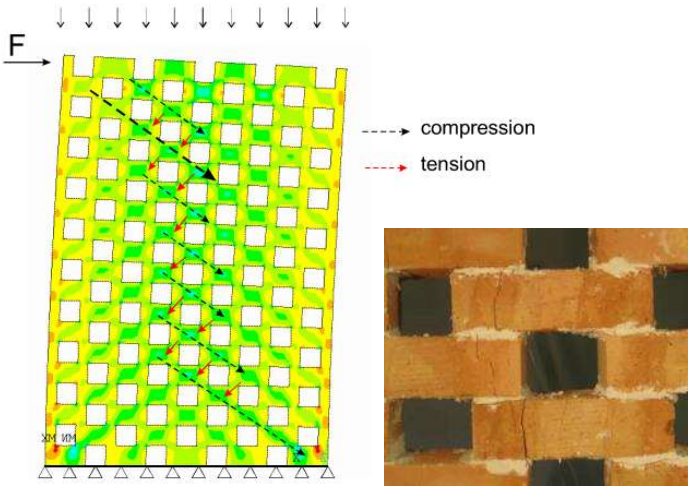


Figure 14. a) Shear force-Displacement-Line of a perforated masonry wall;



Ortlepp, Technical Univ. of Dresden

- Results:
  - The maximum strength of a solid wall is 10% higher compared to the perforated specimen
  - Compared to a solid reference wall, the perforated wall could bear half of the horizontal force

25

Masia et al, Univ. of Newcastle

- Goals:
  - Assess the behavior of unreinforced lattice masonry walls subjected to lateral out-of-plane pressure loading
  - Predict the panel strengths using AS3700 (Australian masonry code) provisions and determine suitability of the provisions for the design of lattice masonry

13TH CANADIAN MASONRY SYMPOSIUM
HALIFAX, CANADA
JUNE 4TH – JUNE 7TH 2017
DALHOUSIE UNIVERSITY

FLEXURAL STRENGTH OF UNREINFORCED LATTICE MASONRY WALLS SUBJECTED TO LATERAL OUT-OF-PLANE LOADING

Masia, Mark[1]; Simundic, Goran[2] and Page, Adrian[1]

ABSTRACT

Lattice masonry is a form of construction in which the mortar perpend joints are left unfilled and the masonry units are spaced along the courses to leave gaps between adjacent units. When designing such walls to resist out-of-plane lateral loading due to wind and/or earthquake actions, the Australian Standard AS3700: Masonry Structures provisions for one way vertical bending can be applied by using a section modulus based on the net bedded area. However, the provisions for horizontal bending require that the masonry be constructed with all perpends completely filled and therefore lattice masonry falls outside the scope of AS3700 for horizontal bending. The paper describes a preliminary study to assess the behaviour of unreinforced lattice masonry walls subjected to lateral out-of-plane pressure loading. Six lattice masonry panels, 14 courses (1194 mm) high x 4 units with 90 mm gaps (1190 mm) long, were constructed using extruded clay bricks (230 mm long x 110 mm wide x 76 mm high) and 1:1:6 (cement : lime : sand) mortar. Three panels were tested in one way vertical bending and three were tested in one way horizontal bending. The load versus deformation behaviour and the observed failure modes are reported. The AS3700 provisions for solid masonry were used to predict the panel strengths and an assessment of the suitability of the provisions for the design of lattice masonry is made.

KEYWORDS: *flexural strength, lattice masonry, out-of-plane loading*

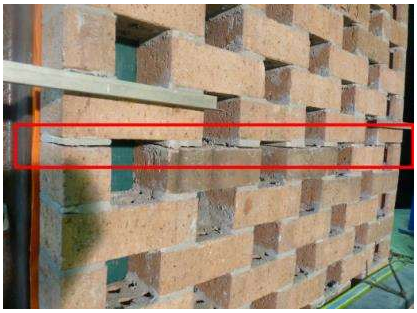
INTRODUCTION

Lattice masonry (also known as hit and miss brickwork) is a form of construction in which the mortar perpend joints are left unfilled and the masonry units are spaced along the courses to leave

26

Masia et al, Univ. of Newcastle

- Six walls tested: 3 panels in one-way vertical bending and three in one-way horizontal bending
- Air bag used for loading; gross area used for moments
- Type N mortar



27

Masia et al, Univ. of Newcastle

- Results:
  - Panels subjected to **one-way vertical bending** failed in a non-ductile mode via bed joint cracking which occurred suddenly at the peak load along single course close to panel mid-height
  - Strength predictions using AS3700 using mean material strengths and capacity reduction factor of one, over-predicted the experimentally observed strengths
  - Panels subjected to **one-way horizontal bending** also displayed non-ductile failure modes with no observable damage prior to a sudden failure surface developing at peak load
  - For the one-way horizontal bending, the strength predictions based on mean material properties under-predicted the experimentally observed panel strengths

28

Structural Design of Perforated Screen Walls

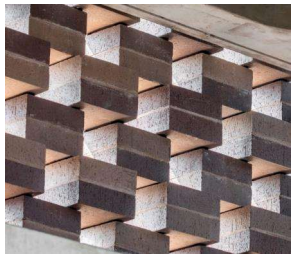
- Empirical design used in the past
  - Appropriate for landscape walls which are usually short walls experiencing minor wind loading
- Cannot use prescriptive methods for anchored masonry veneer since veneer ties aren't typically used (no backing)
- Past experiences and equations used with solar screen tile do not apply here

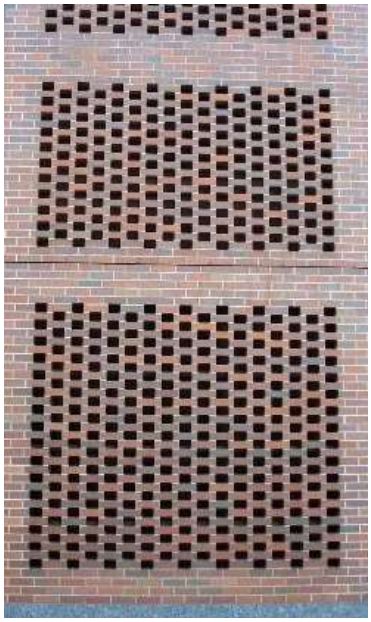
Photos source: Elgin Butler

29

Structural Design Models

- Perforated screen spans horizontally between "pilasters" or vertically between solid sections
- Anchor brick screen back to posts
- Vertically reinforced through core holes
- High-bond (polymer) mortars



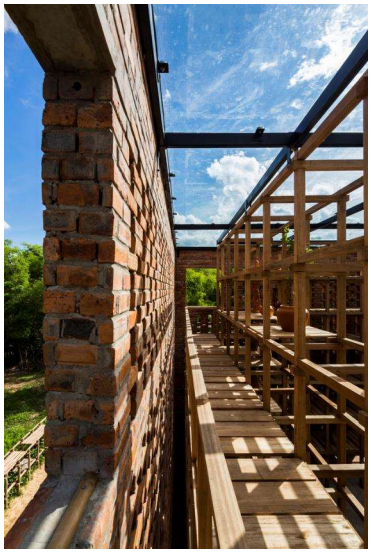


30

Structural Design of Perforated Screen Walls

- Increase wall thickness to increase bonding area allowing greater span between supports

Terra Cotta Studio, Dien Phoung, Vietnam
Tropical Space Architects



Photos source:
Oki Hiroyuki

31

Structural Design of Perforated Screen Walls

- Change to rainscreen-type wall with each unit supported individually

Sentry Insurance, Stevens Point, WI
Flad Architects

Fabrik by Shildan

32

Wind Loading for Perforated Screen Walls

- Determination of wind loads
  - Open area reduces material resisting wind, so wind loads are lower… but, there are drag forces from wind flowing through the screen
- Wind loads on perforated wall should be assumed to be the same as a solid (non-perforated) wall for determination of wind loads… until further research proves otherwise

33

Structural Design of Perforated Screen Walls

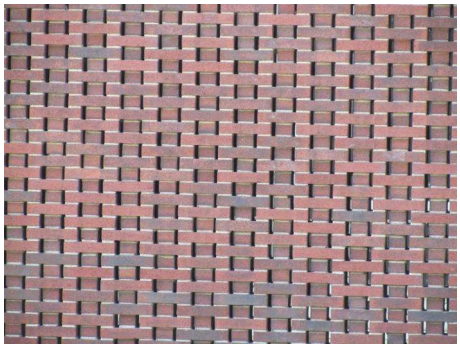
- Summary
  - Cannot follow prescriptive requirements for anchored veneer walls
  - Use engineered design of unreinforced masonry (assuming no vertical rebar) taking into account area of bonding, flexural tensile strength of masonry and shear strengths
  - Design as reinforced masonry element
  - Various design strategies exist, but all require some type of structural analysis

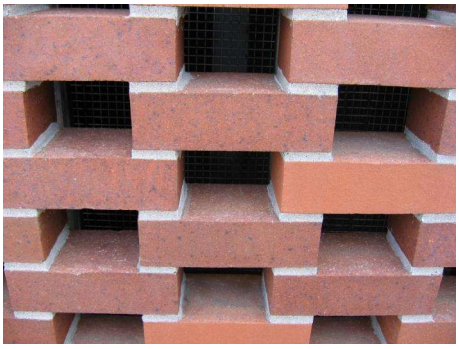
34

Detailing of Perforated Screen Walls

Detailing of Perforated Screen Walls

- Size of openings will affect aesthetics as well as structural capacity
- Minimum contact area (bearing) is usually 1” on each end; more may be necessary depending on design





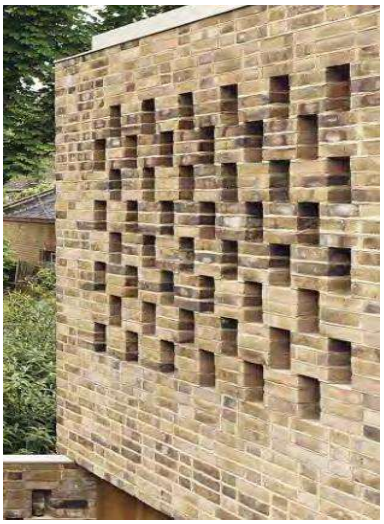
Detailing of Perforated Screen Walls

- Spacing ratio: gap/(gap + unit length)
- For modular size brick (7 5/8” long)
  - 3/8” gap, SR = 0.047
  - 5 5/8” gap, SR = 0.425
- For Utility size brick (11 5/8” long)
  - 3/8” gap, SR = 0.031
  - 9 5/8” gap, SR = 0.453
- To maintain min. 1” bearing, SR ≈ 0.4 or less

Detailing of Perforated Screen Walls

- Different effects (size, shapes, bonds)

Photo source: Dezeen.com



Detailing of Perforated Screen Walls

- Perforated screen walls are open to the weather
  - Saturation of brick units
  - Coping details critical, if used as freestanding wall
  - Movement joint details no different (maybe?)

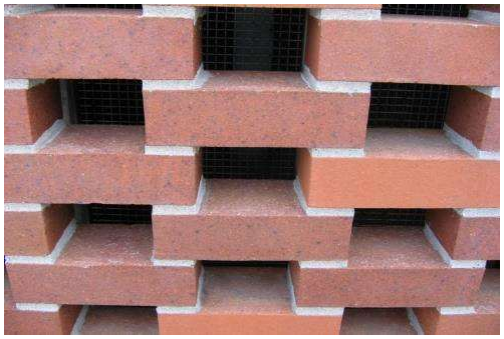


Photo source: Barbara Valianti GuruShots

39

Detailing of Perforated Screen Walls

- Solid units are preferred in freeze/thaw climates
- Brick having properties of a paving brick may provide improved durability (higher comp. strength, lower absorption)



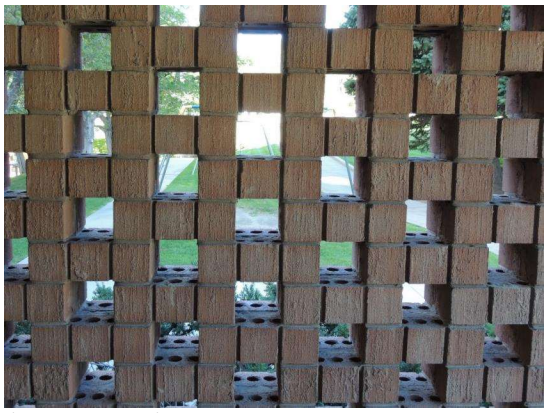
Seaport Hotel, Boston, MA

Schoolcraft College, Biomedical Technical Center

40

Detailing of Perforated Screen Walls

- Cored units have been used, but there are risks involved especially in freeze/thaw climates



Photos courtesy Interstate Brick

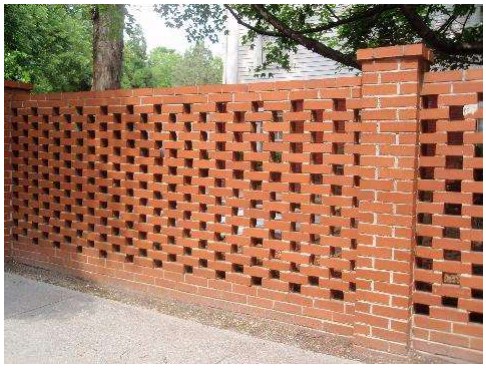
Univ of Utah Student Housing

LDS Church

41

Detailing of Perforated Screen Walls

- Coping Details (if not used in building façade)
  - No different than other walls (flashing, overhang, etc.)
  - Avoid brick rowlock courses



Schoolcraft College, Biomedical Tech Ctr, Livonia, MI

42

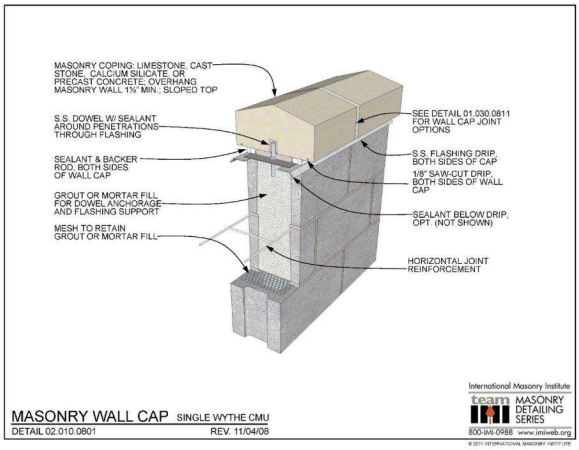
Detailing of Perforated Screen Walls

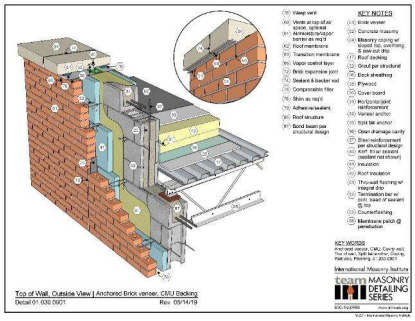
- Coping Details
  - Overhang and drip

43

Detailing of Perforated Screen Walls

- Coping Details (from IMI's Masonry Detailing Series)





44

Detailing of Perforated Screen Walls

- Flashing at base of perforated screen?
  - No, since this affects bonding and structural strength of wall

Quin Curtis Center, WV Univ.

45

Detailing of Perforated Screen Walls

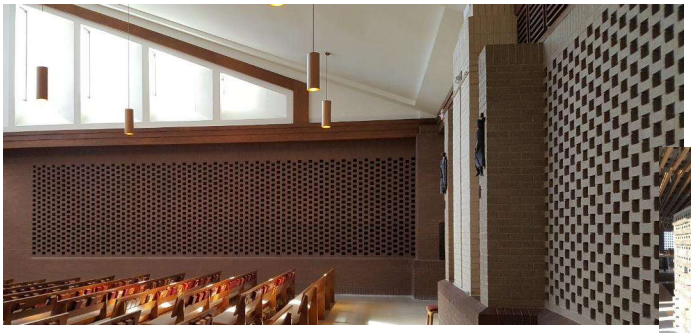
- Movement Joints in clay masonry screen walls
  - Consider vertical EJs at typical spacing (i.e. every 20-25')
  - Openings could allow for expansion, but often solid sections of wall will need to have regular EJ spacing
  - Movement joints should NOT be placed at edge of perforated panel, depending on design

Schoolcraft College
Livonia, MI

46

Interior Perforated Screen Walls

- Not subject to weathering or wind loads



St. Raphael Catholic Church, Raleigh, NC

Hyatt Global HQ
Chicago, IL

Photo courtesy Robb Haukohl

47

Case Studies of Perforated Screen Walls

The Concave House, Liaoning Province, China

Photos source Dezeen.com

48

Kolumba Museum, Cologne, Germany

- Peter Zumthor

Photos source: Dezeen.com

49

Kolumba Museum, Cologne, Germany

- Amount of perforations small and scattered compared to other projects

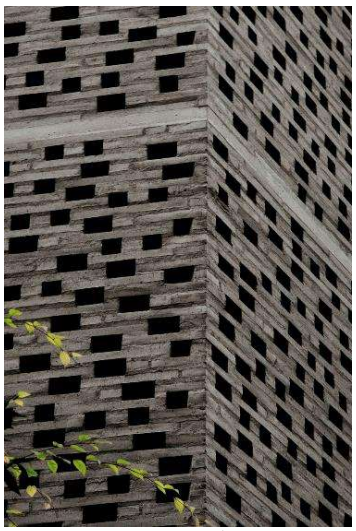
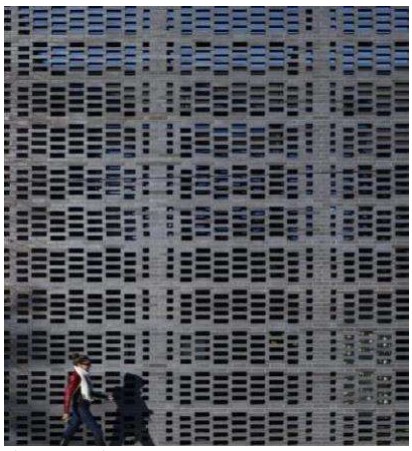


Photo source: Dezeen.com

50

Weave House, Chicago, IL

- Studio Gang designed perforated wall to enclose courtyard

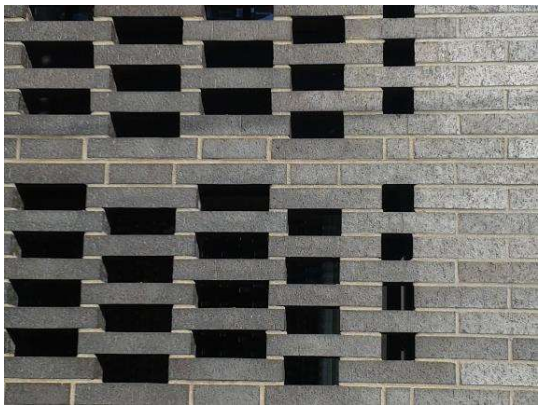


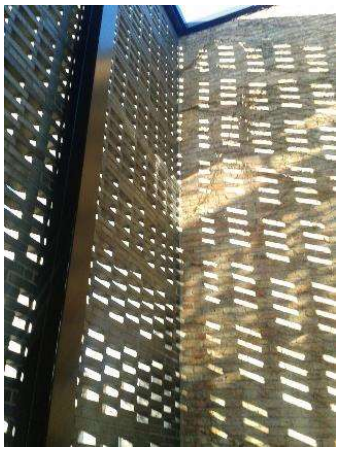
Photos source: Studio Gang

51

Weave House, Chicago, IL

- Joint reinforcement used in horizontal bands that are then anchored to steel columns





52

Emiliano Zapata 167 Apartments Mexico City, Mexico

- HGR Arquitectos
- Located in high seismic zone (2017 Puebla earth-quake magnitude 7.1 resulted in no damage)

53

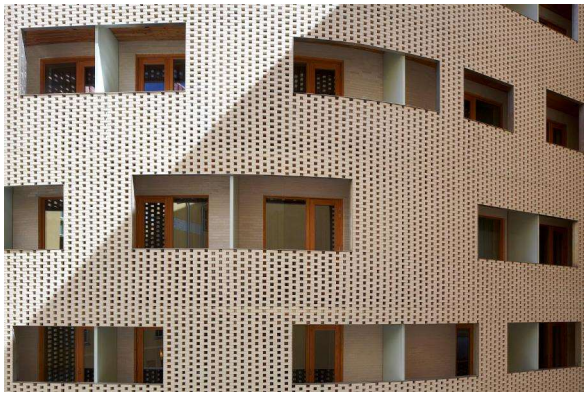
Emiliano Zapata 167 Apartments Mexico City, Mexico

- Screen walls were attached to the concrete structure with steel reinforcing bars through specially cored brick

54

Paasitorni Hotel & Conference Center Helsinki, Finland

- K2S Architects



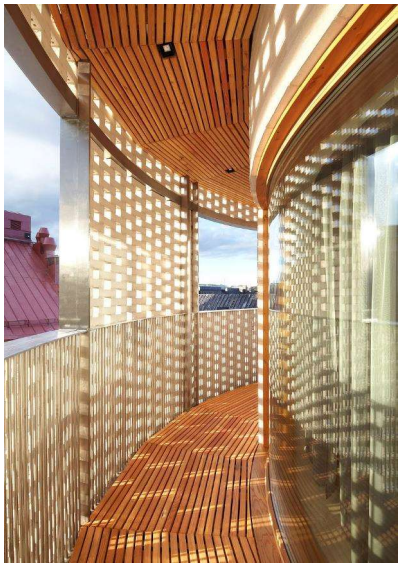
Photos source: ArchDaily.com

55

Paasitorni Hotel & Conference Center Helsinki, Finland

- Brick units are cored with “oval shaped holes in both ends to allow tolerance for the steel supports used to strengthen the wall.”

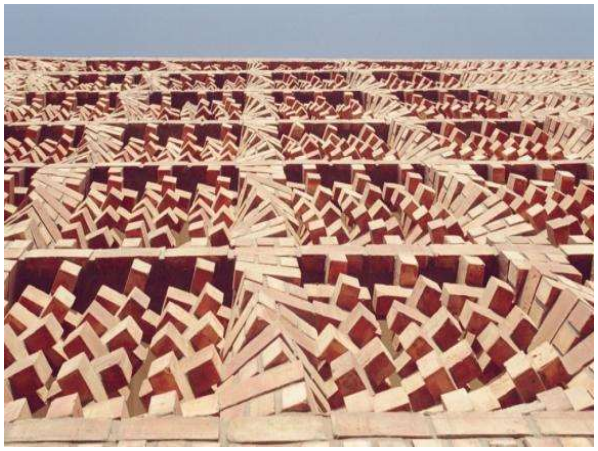
Photos source: ArchDaily.com



56

South Asian Human Rights Documentation Centre New Delhi, India

- Anagram Architects



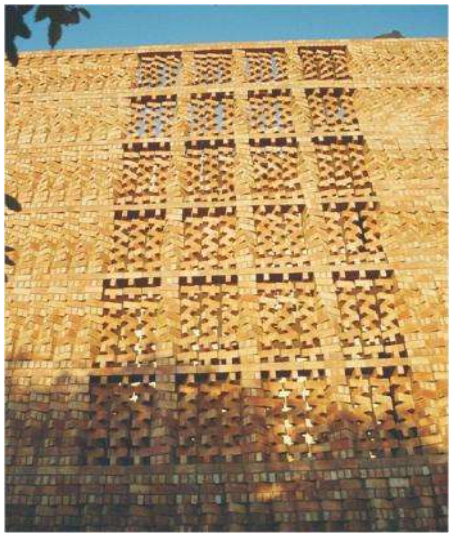


Photo source: Dezeen.com

57

South Asian Human Rights Documentation Centre New Delhi, India

- "The construction of the screen wall was a result of a five-week process devising masonry techniques on site. From verification of plumbline to the structural bonding of the brick courses, methods of bricklaying were devised through a deep on-site collaboration between the masons and the architects."

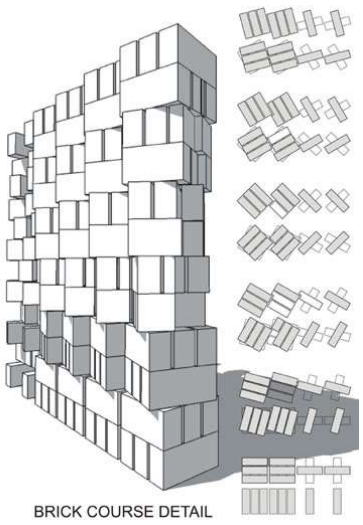


Image source: Dezeen.com

58

South Asian Human Rights Documentation Centre
New Delhi, India

- "In the porous central portion of the façade, brickwork is reinforced horizontally by a laying a thin section (95 mm x 125 mm) [3.9 in. x 4.9 in.] reinforced concrete beam along the cavity created by the missing central brick."

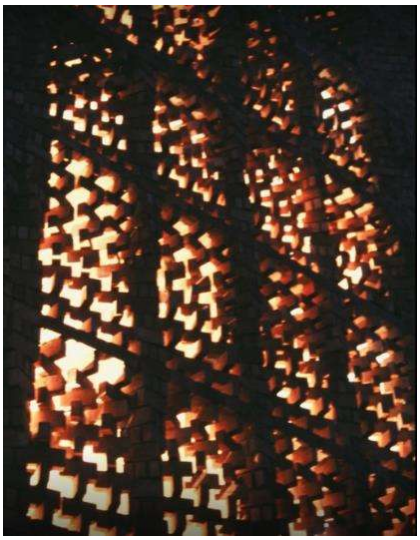


Photo source: Dezeen.com

59

Gantenbein Winery
Flasch, Switzerland

- Gramazio & Kohler
- Perforated screen wall using brick angled to create pattern, computer designed

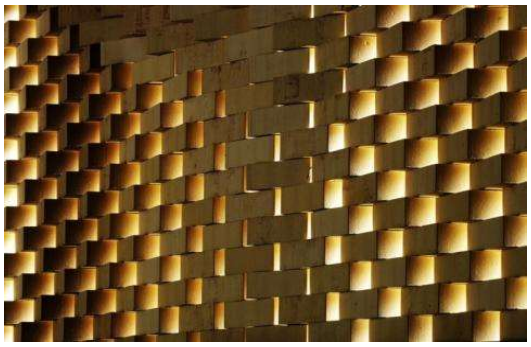


Photo source: Dezeen.com

60

Gantenbein Winery
Flasch, Switzerland

- Used epoxy mortar; prefabricated (off-site) elements constructed with robotics

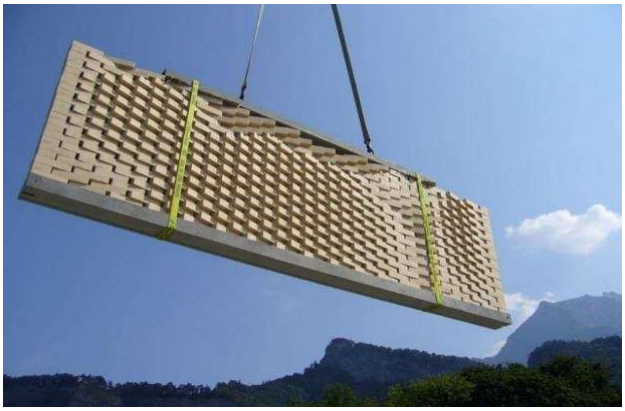


Photo source: Dezeen.com

61

Tate Modern Switch House
London, England

- Herzog & de Meuron

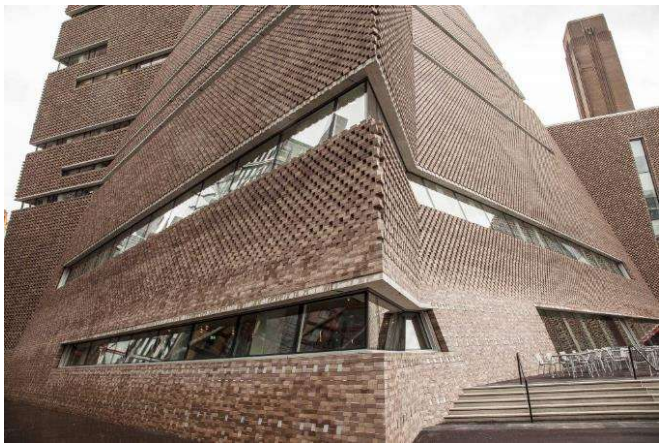


Photo source: Dezeen.com

62

Tate Modern Switch House
London, England

- Herzog & de Meuron
- Developed new 3D setting-out tools to maintain tolerances and worked closely with mason
- Full-scale façade mock-up used
- One goal was to eliminate movement joints

Photo source: Dezeen.com

63

Tate Modern Switch House
London, England

- Paired brick bonded with polymer mortar
- Connections made using elastomeric joints and stainless steel pins and shims

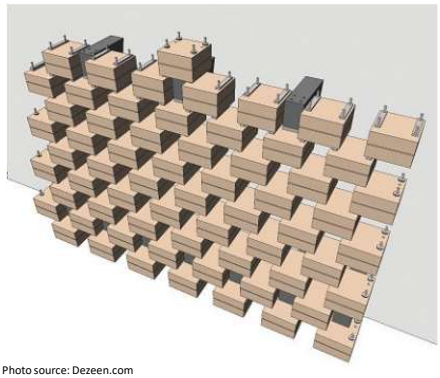
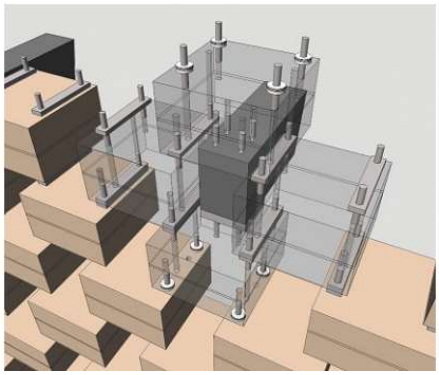


Photo source: Dezeen.com



64

Tate Modern Switch House
London, England

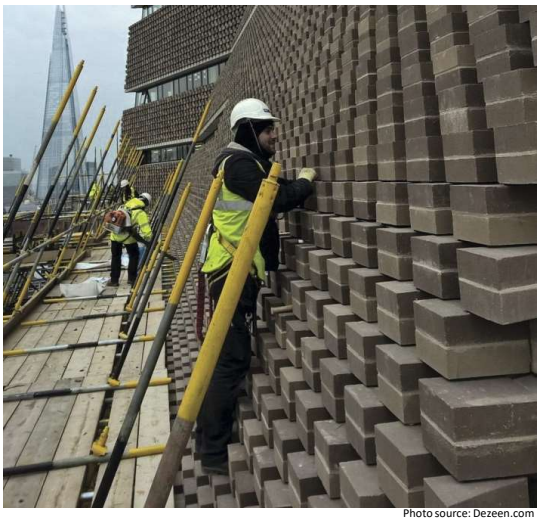


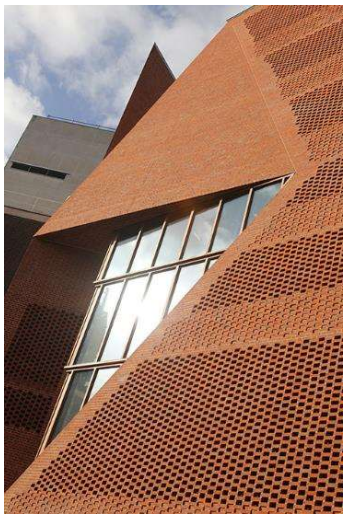
Photo source: Dezeen.com

65

Saw Swee Hock Student Center,
London School of Economics

- O'Donnell & Toumey

Photo source: Dezeen.com



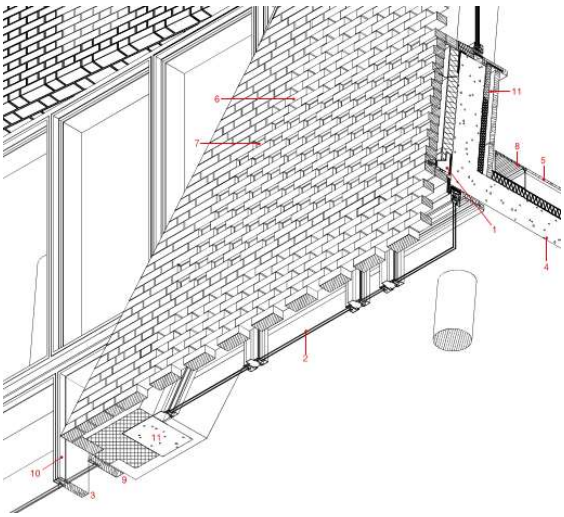
66

Saw Swee Hock Student Center, London School of Economics

- Brickwork supported at story levels with continuous horizontal angle
- Tied back to the masonry structure with wall ties where possible
- Perforated areas were tied back to vertical stainless steel wind posts at approximately 900 mm (35 in.) centers (coinciding with brick overlap joints) which were in turn supported at story heights

67

Saw Swee Hock Student Center, London School of Economics



68

Arrupe Hall, St. Joseph University

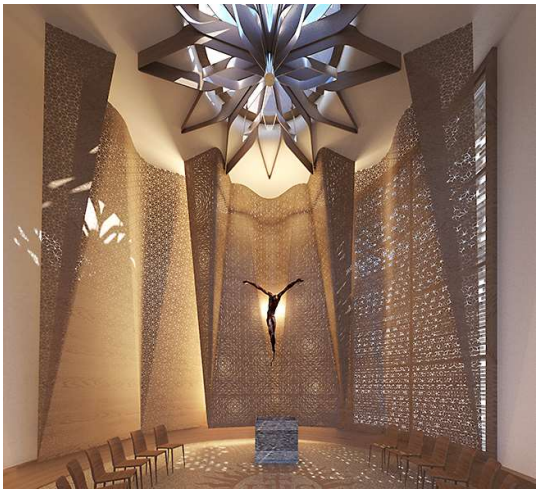


Image source Moto Design

Arrupe Hall, St. Joseph University

- Currently under construction

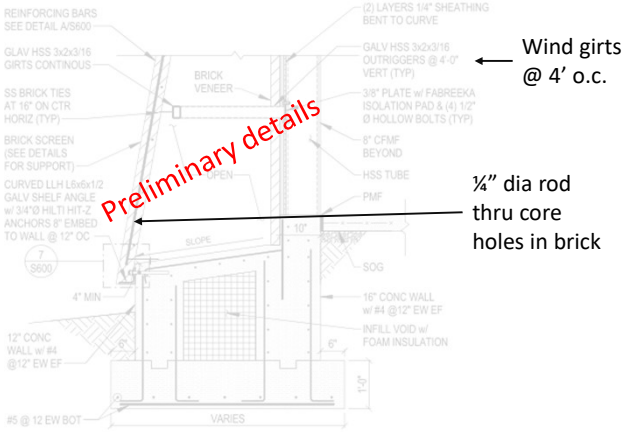


Image source Moto Design and Keast Hood

Computer Aided Design of Perforated Screen Walls

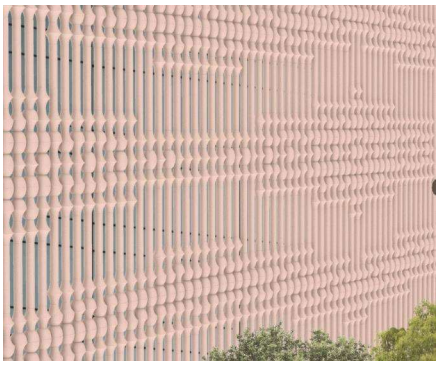
- Digital fabrication allows these wall types to possess great complexity

- Examples from Gramazio and Kohler and ETH in Switzerland; Georgia Institute of Technology; and Harvard Graduate School of Design among others

71

Future Uses?

- Past Winners of IMI's Joan B. Calambokidis Innovation Award



Iowa State Univ. faculty
3D printed ceramic facade

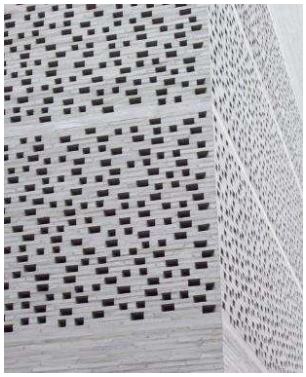
Chao Wei
Alterable Brick Wall

72

Further Research

- Wind tunnel testing of loads on perforated walls to determine actual wind loads
- Actual structural capacity of unreinforced walls





73

Conclusion

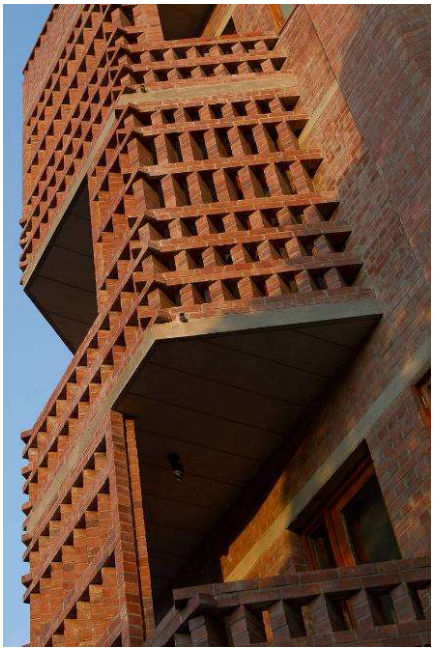
- Perforated screen walls have a long history of use in landscape applications
- Their use continues to increase in building facades
- Information provided can assist in design and detailing walls to perform as expected
- Use trained craftworkers with experience to fulfill design expectations
- Continue to be creative!

74

Photo source: Dezeen.com

75

Photo source: Dezeen.com



76

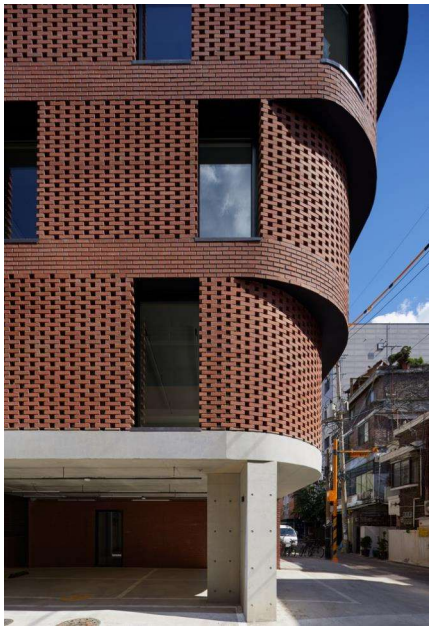


Photo source: ArchDaily.com

77

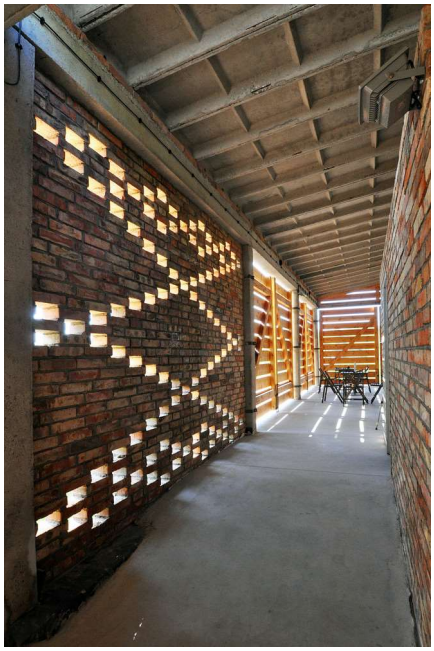


Photo source: Dezeen.com

78

Further Reading

- Trimble, “Design of Unique Landscape Walls and Their Use in Building Façades”, 12th Canadian Masonry Symposium, 2013
- Masia et al, “Flexural Strength of Unreinforced Lattice Masonry Walls subjected to Out-of-plane Loading”, 13th Canadian Masonry Symposium, 2017
- Masia et al, “Experimental testing of unreinforced lattice masonry walls subjected to out-of-plane pressure loading”, 17th International Brick and Block Masonry Conference, 2020
- Hit and Miss Brick Screen Fact Sheet, Think Brick Australia
- Visit my Pinterest site for more examples: bricktrimble

79

80