



347

Design, Function, and Gender in a Place of Discovery:

Qatar University Main Library

MARK DAVID MAJOR, HEBA O. TANNOUS, RAGHAD ALATOOM, ALJAZI AL-BANAI,

GHALYA N. AL-MAADEED, HANAE A. TAHA & LABEEN A. ELLATH

DEP. OF ARCHITECTURE AND URBAN PLANNING, QATAR UNIVERSITY, QATAR

ABSTRACT

Libraries have been a source of fascination for space syntax researchers for a long time. The paper reviews the results of Post-Occupancy Evaluation and space syntax analysis of the Qatar University Main Library. Opening in 2012, the library quickly became the effective ‘heart’ of the campus. Due to the building’s strategic importance became a case study for complex buildings research in the Department of Architecture and Urban Planning, College of Engineering at Qatar University in 2020. The goal was to learn about the design, programming, and people’s use of the library, including cultural adaptation for gender segregation. The study includes movement and space use observations, a building program survey, and space syntax modelling. Based on the findings, the library is a well-designed built environment. It functions efficiently, even with ‘awkward’ entry and vertical circulation for males due to gender segregation in its building program. It also reveals the library’s importance in the university’s social life, especially for females.

KEYWORDS

gender, library, movement, post-occupancy evaluation, space syntax

1 INTRODUCTION

For a long time, libraries and museums have fascinated space syntax researchers, including Bill Hillier, Julianne Hanson, Ruth Conroy Dalton, and Sophia Psarra. In part, the arduous 35-year history of constructing and opening the ‘new’ British Library near the University College London (UCL) campus initially fed this interest. In its early years, libraries and museums were key case studies of the Complex Buildings Module on the MSc in Architecture: Advanced Architectural



Studies course at UCL. A long — but hardly exhaustive — bibliography of space syntax research involving libraries includes Conroy, 2001; Koch, 2004; Psarra, 2005; Psarra, 2007; Li & Klippel, 2010; Tzortzi, 2010; Dalton, 2011; Li & Klippel, 2012; Zook & Bafna, 2012; Kuliga, Dalton, & Hölscher, 2013; Capillé & Psarra, 2014; Sailer, 2015; Capillé & Psarra, 2016; Dalton & Hölscher, 2016; Sato et al., 2017; Kuliga et al. 2019; Askarizad & Safari, 2020.

The standard definition of a library is a building or room containing collections of books, periodicals, and sometimes films and recorded music for use or borrowing by the public or the members of an institution. The word derives from Late Middle English via Old French, from Latin *libraria* ‘bookshop,’ feminine (used as a noun) of *librarius* ‘relating to books,’ from *liber*, *libr-* ‘book.’ Another common word to describe a library is *bibliotheca*, which derives from Latin meaning ‘library, collection of books,’ itself from Medieval Latin meaning ‘Bible’ if we compare with the (now obsolete) Old English *bibliothēce* for Bible (Oxford English Dictionary). These definitions seem inadequate for describing the library as a contemporary building or social place. Libraries are both social reservoirs of knowledge and places of discovery. According to the National Institute of Building Sciences *Whole Building Design Guide*, “library space types are areas where bound paper documents, film, or magnetic media are stored (and) may include both open and closed storage systems and moveable shelving systems, and be applicable to file rooms and other dense storage of material in conditioned office environments, (which are) assumed to be general purpose, and may include display spaces and reading, meeting, and electronic workstations, as defined by the desired level of access to materials being stored” (Prowler & Vierra, 2021). Libraries include archival and storage spaces, controlled environments for climate and access, exhibition and display spaces, social spaces such as meeting rooms and common areas for the public’s use, subject to the requirements of the first two, i.e., controlled access for storage of archival materials (Prowler & Vierra, 2021).

Qatar University Main Library (QUML) strives to nurture students' academic and research aspirations and support the community's educational and professional needs. The library provides high-quality information services to the Qatar University (QU) community, its local and international partners, and all Qatari society with an extensive book collection in print and digital format (Source: QUML). It sits on a building plot of ~26,725 square meters (m²), about 400 meters (m) north-easterly from the campus' geometric centre near the QU Women's Engineering Building (Figure 1). The library straddles the boundary between the campus's male, female, and mixed parts. The QU Research Complex and new College of Engineering (CENG) buildings are adjacent across the street to the north. There is an open plaza, parking lots, Ibn Khaldoon Hall, Qatar National Bank building to the east, a plaza, parking lots to the west, and an open plaza, green spaces, CENG Research Centre, and the QU Mosque to the south. The building is easily accessible for students and faculty members from the surrounding buildings. However, the west entrance is restricted the female students only. The building consists of five (5) main floors, including a basement with service offices and underground parking.



Figure 1: View of (left) the QUML southern façade in 2017 and (right) QUMI building plot (outlined in red) within the immediate context of the QU campus from 1,000 meters in 2021 (Source: QUST-2-CENG-2020-16/Google Earth/Image©2021, Maxar Technologies).

Since its opening in early 2012, QUML has become the effective ‘heart’ of the campus. Given the building’s strategic importance, it was a case study of the ongoing Comfort/Complexity/Configuration and Use in the Built Environment (CUBE) research project in the Department of Architecture and Urban Planning (DAUP) CENG at QU in 2020. It is the third such research grant involving primarily undergraduate students (CUBE¹: QUST-2-CENG-2018; CUBE²: QUST-2-CENG-2019-12; CUBE³: QUST-2-CENG-2020-16) (Major et al., 2019). Post-Occupancy Evaluation (POE) studies can vary in scope depending on building type and size, but the focus usually assesses the design and functioning of the building. The goal of CUBE³ was to learn about the relationship between design, programming, and people’s use of QUML, including a cultural adaption of its design by floor and area for gender segregation purposes. The study included observations of movement and space use, a survey of building programming, and axial, convex, and Visibility Graph Analysis (VGA) modelling of the spatial layout.

The research in this paper reviews the results of the POE study and space syntax modelling of the QUML. The paper argues that QUML is a well-designed built environment based on the study’s findings. It functions efficiently for its purpose, even with an ‘awkward’ entry and vertical circulation sequence for male students due to the incorporation of gender segregation in the building program. Most male students tend to use the library primarily for study purposes. Female students more fully utilise the library, especially for social interaction and study purposes. Everyone uses the library as a cut-through route from one degree to another, depending on total usage by type, especially faculty. Spatial modelling also identifies the importance of the east-west central axis in the building on every floor and the north-south axis in the entire building due to the loading of most vertical circulation (elevators/stairs) and metric area of the library bookshelves areas on the library floors.

2 RESEARCH DESIGN AND METHODOLOGY

Researchers conducted the POE study to investigate and evaluate the functioning of QUML in 2020. The study involved two rounds of direct observation and survey fieldwork in January and March 2020 before lockdown restrictions for COVID-19 in Qatar. The exterior climate was sunny and pleasant (27°-21° C). During November and December, there was follow-up fieldwork when the exterior climate was warm but pleasant (29°-24° C), three months after lifting most restrictions due to the global pandemic. The study effectively took ten months spread out over the year with a pause during COVID-19 lockdown, so it was limited in scope.

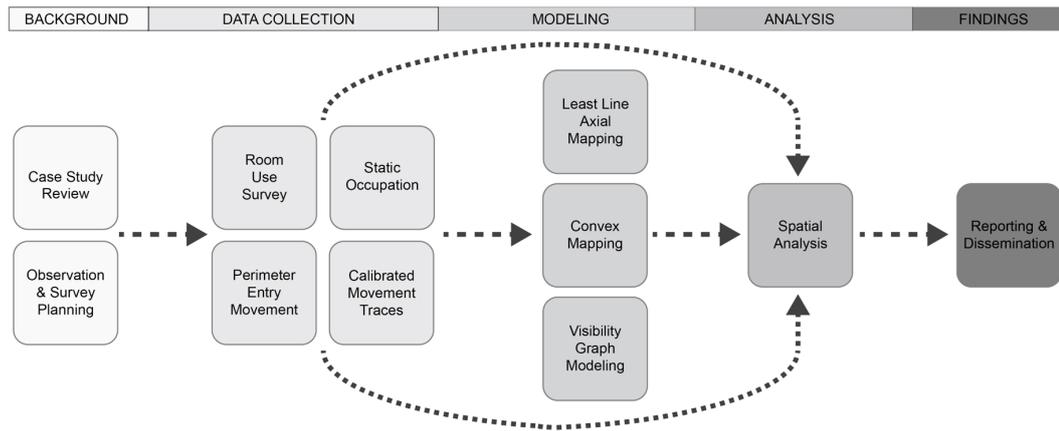


Figure 2: Research design illustrating the methodology of the CUBE³ study (Source: QUST-2-CENG-2020-16).

The study occurred in five stages. The first was a literature review, including a search for specific information about QUML and site visits to develop a plan for observing space use and movement over several days to compile a typical weekday profile (Sunday-Thursday) (Figure 2). There is significantly lower use of QUML during the weekend the weekdays. The next stage consisted, initially, of observations of entries at the perimeter and an extensive survey of room use in the building. Second, there were observations of static occupation (sitting, standing, interacting) in QUML and discreet ‘passive’ following (meaning no interaction) of people entering the library from every access point, calibrated to the entry/exit counts based on gross percentages of use. During the third stage, researchers conducted extensive computer modelling of QUML using space syntax methods, including convex mapping, least-line axial mapping, and Visibility Graph Analysis (VGA). The latter involved making modifications to the AutoCAD floor plan provided by the QU Campus Facilities Department for processing in DepthMapX (Hillier, 1996; Sailer et al., 2016). The data collection and modelling of the second and third stages fed the spatial analysis in the fourth stage. Researchers completed the last phase by compiling all this data collection, analysis, and findings in reports for dissemination.

QUML consists of five (5) floors, including a basement (G-1) level with offices, service spaces, and an access point from an underground parking garage (Figure 3). For this study, researchers ignored the access point and other spaces associated with parking. The other floors are primarily for students and

academic/administrative staff, including bookshelves, study areas, lounges, meeting rooms, service areas, prayer areas, and computer labs.

The building is at the heart of the QU campus between the male and female campuses and mixed-gender campus. The main (north) entrance faces the new College of Engineering, QU Research Centre, and College of Business and Economics. This entrance is accessible from a principal street at the centre of the campus and closest to a heavily used bus and vehicle drop-off point. Side entrances face the QU Admission and Registration Buildings to the west and the Administrative Affairs building and student/faculty parking lots to the east. The south entrance faces the existing Male College of Engineering in the BCR Corridors.

The design of the building's layout follows an orthogonal layout with the main circulation axis from (more or less) east-to-west from the male to the female campus and a secondary cross-axis circulation, connecting perpendicular to the main entry from north-to-south (Figure 4). The floor plans (excluding the basement level) divide into three wings conjoined together in a focal area. It composes an atrium with the central wing consisting of bookshelves and study areas on the ground floor. The other two wings have offices, labs, and social spaces such as the cafes on both the male and female sides of the ground floor. The ground floor serves as the primary public floor, accessible to everyone. There is a security door between the male and female sides of QUML on the ground floor, but whether it is open or closed (with key card access) varies depending on public events and activities on any specific day or time in the library. The original design of the building envisioned shared use amongst all students.

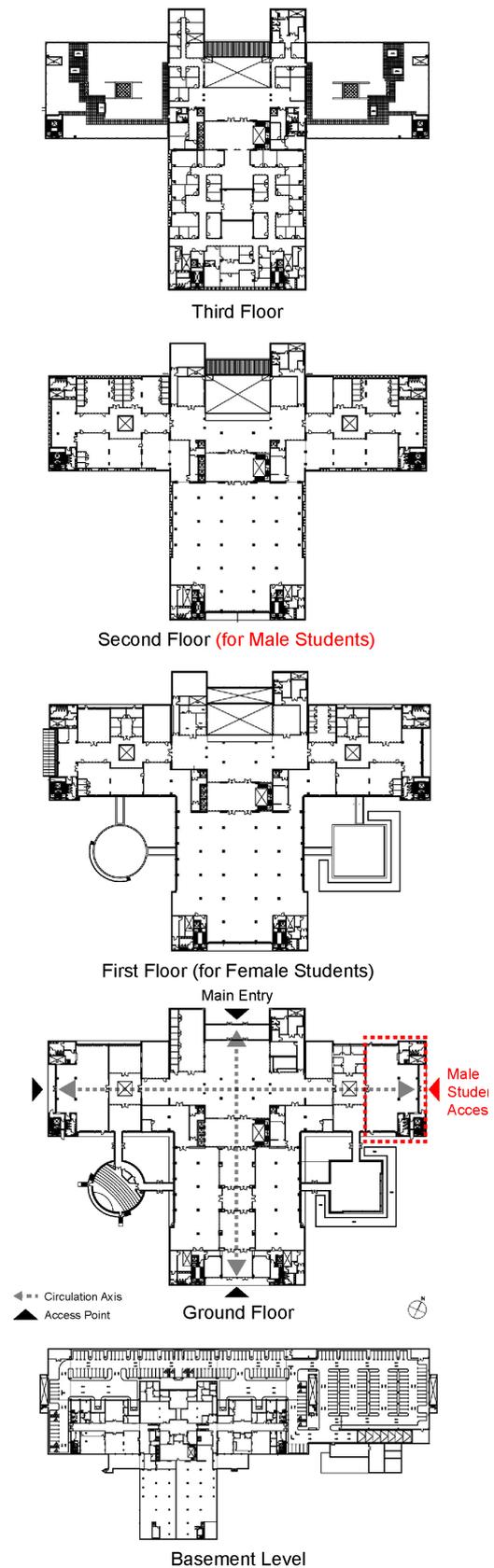


Figure 3: Floor plans of the QU Main Library (Source: QU). Note: Basement level is not to scale with other floors.

However, adaptations to the layout restrict male students to a large eastern atrium on the ground and the second floor itself. Female students have full access to the ground floor, with the 1st floor reserved for female students only. Due to this arrangement, there have been minor adaptations to the original layout.



Figure 4: Ground floor views (left) looking east from male side to the female side along main east-west axis with the main (north) entrance to the left in the centre and (right) looking north from the restricted (south) entrance along the north-south cross-axis towards the main (north) entrance of QUML when closed in March 2021 (Source: QUST-2-CENG-2020-16).

QUML is easily accessible for students and faculty members from the surrounding context and buildings. However, under normal circumstances, a restricted western entrance is for female students only, and southern doors are for emergency egress. During the follow-up fieldwork, there was limited access to the main entrance for only female students and the eastern entrance for only male students due to COVID-19 pandemic restrictions. These temporary restrictions arising from the global pandemic did not affect the study's findings. Follow-up field work only filled some small gaps in the research associated with entry from the main (north) entrance and double-checking of the building program survey.

3 FINDINGS

3.1 People and Time

During the first round of fieldwork, observers conducted a room use survey of nine hundred (900) spaces on five (5) floors. The building use survey included qualitative observations to assess any modifications to the original floor plans for adaptive re-use for specific functions. A few instances incorporate gender segregation measures between male and female students in the building. Observers also sampled entry/exit counts at the four (4) access points to the library for two minutes every half-hour (top and bottom 30 minutes of each hour) from 7 am until 5 pm on the weekdays. Researchers excluded the access point from the underground parking garage.

Entry/exit counts accounted for user gender and category, i.e., female/male students, male/female faculty and staff, etc. For the entry/exit counts, researchers directly observed 947 people, which projects to 7,103 users per day of QUML. Based on the entry/exit counts, 60% of the users are female students. Male students constitute 18.5% of the building's users. The remaining users of QUML are faculty (10%), service staff (10%), security staff (1%), and visitors (1%). This ratio



seems reasonable considering the female-to-male student ratio at QU, i.e., 3-to-1 (**Table 1**). Students and faculty account for 88.5% of the users of QUML

Table 1: Demographics of building users of QUML based on entry/exit counts sampling over an entire weekday from 7 am to 5 pm (Source: QUST-2-CENG-2020-16).

TYPE	TOTAL # OBSERVED	PERCENTAGE
Student (Female)	567	60.0%
Student (Male)	174	18.5%
Faculty	93	10.0%
Service Staff	96	10.0%
Security	10	1%
Visitors	7	0.5%
Total	947	100%

During the second round in March and subsequent follow-up fieldwork in November-December, researchers conducted movement observations tracking the routes taken by a typical one hundred (100) people during the first 10 minutes of their visit – or until they reached their destination, whichever came first – from the ground floor entrances. Researchers calibrated the movement trace observations based on the percentage use of total entries through the ground floor entrances in the entry/exit counts. Researchers also conducted static snapshot observations of QUML, noting every person sitting, standing, and interacting in any public area of the building during a typical weekday from 7 am to 5 pm. Researchers directly observed 4,983 people across five floors for the static snapshots. Of this, 45% of stationary use occurred on the ground floor, 24% on the 1st-floor female portion of the library, and 20% in the male library on the 2nd floor (Table 2). The ground and two library floors account for 89% of total stationary use.

Table 2: Total number and percentage use of each floor of QUML based on the static snapshots of all public spaces over an entire weekday from 7 am to 5 pm (Source: QUST-2-CENG-2020-16).

QUML/FLOOR	TOTAL # OBSERVED	PERCENTAGE
3 rd Floor (Administration)	327	6.5%
2 nd Floor (Male Library)	991	20.0%
1 st Floor (Female Library)	1,228	24.5%
Ground Floor	2,237	45.0%
Basement (Parking/Mechanical)	200	4.0%
Total	4,983	100%

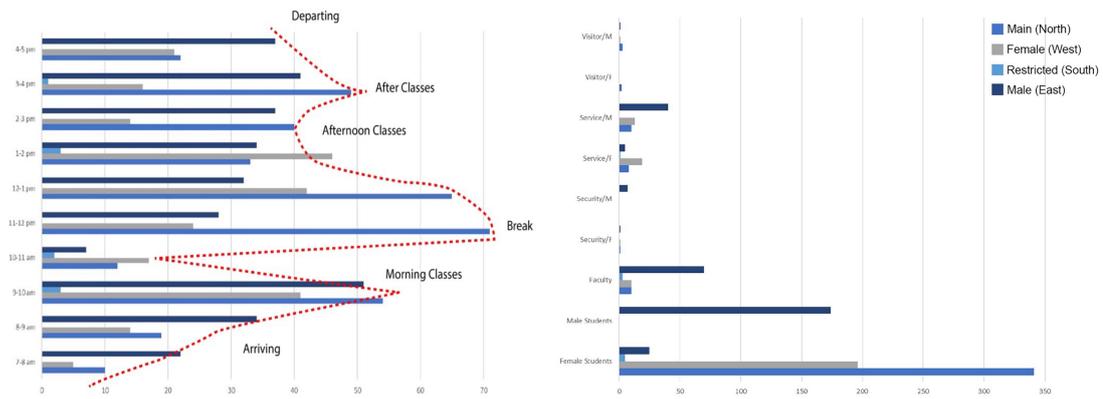


Figure 5: Total observed use of (left) access points and (right) categories of people over time from 7 am until 5 pm in QUML during a typical weekday (Source: QUST-2-CENG-2020-16).

Based on the entry/exit counts over a typical weekday, main entrance use follows a distribution consistent for class schedules with a lunchtime peak (between 11 am-1 pm) and secondary peaks in use before the start of mid-morning classes (9-10 am) and towards the end of the day (4-5 pm) (Figure 5). The female (east) entrance follows a similar distribution of use, except for a notable divergence for 11 am-Noon when most female students utilise the main entrance and a 1-2 pm peak when more students use the female (east) entrance. It indicates female student movement via the library in the context, especially to/from the female side of the QU campus. At the male (west) entrance, there is a much sharper increase in use early in the morning until 9-10 am, and it is the most used access point between 7-9 am due to faculty and male students. There is a sharp decrease during mid-morning classes (10-11 am) and much lower use (relative to the main entrance) during lunchtime. From 11 am onwards, there is a gradual increase in the use of the male (east) entrance until 3-4 pm. The use of the male (east) entrance appears notably higher in the late afternoon. However, in part, it is an artifact of female use split among two access points since main and female (east) entrance use is collectively higher. However, it is due to the surface parking lots accessible via the library on the male (east) side of the campus. Parking on the female campus is accessible to several academic/administrative buildings where movement through the library is unnecessary.

Table 3: Average number of people per hour entering and exiting the four ground level access points of QUML over an entire weekday from 7 am to 5 pm (Source: QUST-2-CENG-2020-16).

QUML ACCESS POINTS	ENTRY (People/hour)	EXIT (People/hour)	TOTAL (People/hour)
Main (North) Entrance	271.5	291.0	562.5
Male (East) Entrance	285.0	199.5	484.5
Female (West) Entrance	186.0	174.0	360.0
Restricted (South) Entrance	6.0	7.5	13.5
Total	748.5	672.0	1,420.5

There are more people per hour entering (+11%) than exiting QUML over the day. Some people remain in the building after the conclusion of the observations at 5 pm, or faculty/staff leave the building via the underground parking garage to account for this difference. The main (north) entrance is the most heavily used access point for entering and exiting, with an average of 563 people/hour

(Table 3). There are marginally more people leaving (+7%) than entering from the main entrance over the day due to the bus stop and drop-off zones for female students outside to the north. Collectively, 20% more people enter than exit via the male (east) and female (west) entrances. However, the male (east) entrance drives this difference since 40% more enter than exit at this location. The male (east) entrance is the second most used access point for entering and exiting with an average of 485 people/hour, in part because the entry of all male students occurs via this entrance. It is also because the male (east) entrance is accessible to everyone, including female students. There are people, especially faculty (105 faculty/hour) and service staff (68 people/hour), regardless of gender, cutting through the library in moving east to west on the campus, meaning they enter at this point and exit in another part of the library. Generally, these are faculty, service staff, and a small number of female students (38 people/ hour) moving from the Research Complex, Administrative Building, or QNB Building via the library to elsewhere. The difference between entering and exiting at the female (west) entrance is only 7%. Because of this, faculty, service staff, and male students are the primary users of the male (east) entrance. Female students are the principal users of the main (north) and female (west) entrances. However, service staff also use these library entrances, though male service staff skew to the male (east) entrance and female staff to the female (west) entrance.

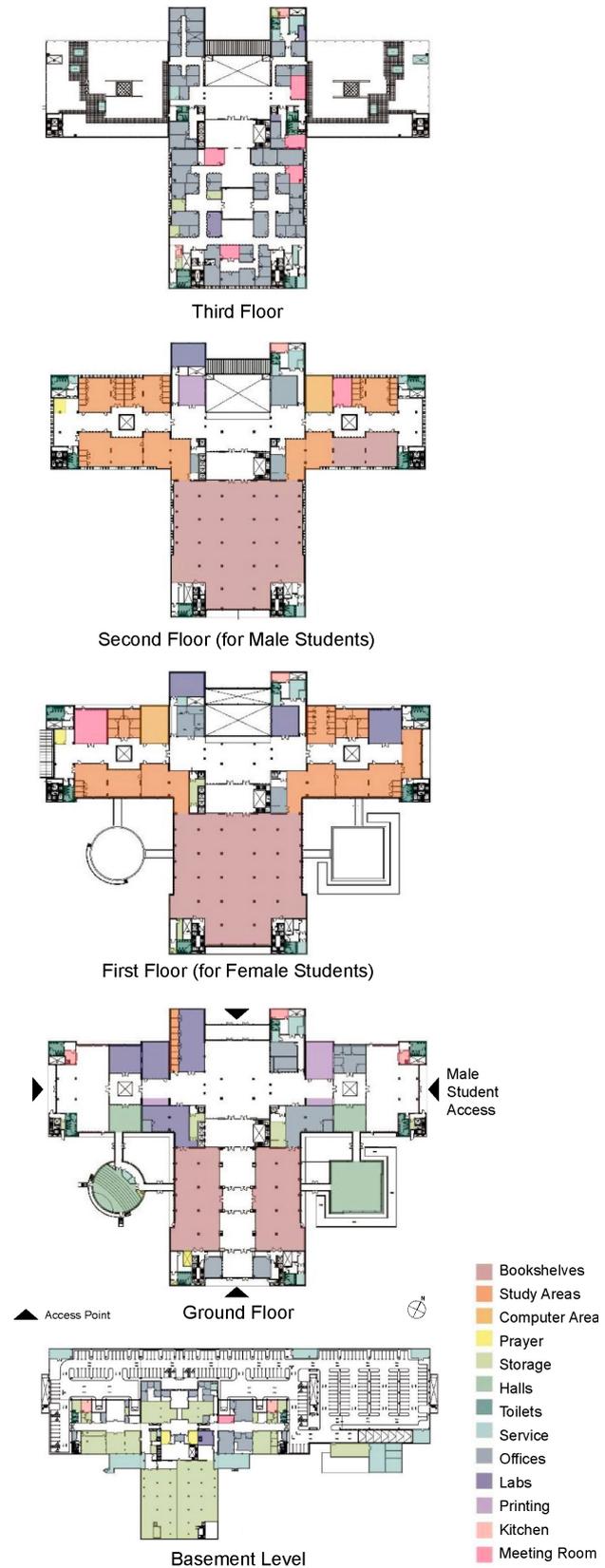


Figure 6: Building use survey of QUML (Source: QUST-2-CENG-2020-16). Note: Basement level is not to scale with other floors.



3.2 Building Use

The building use survey demonstrates the function of principal rooms and spaces across five floors of QUML in 2020 (Figure 6). Researchers did not colour code areas functioning primarily for circulation or parking. Room/space use on the first floor (female library) and second floor (male library) tends to mirror each other, except for slightly more floor area for labs in the female library and bookshelves in the male library. Neither is surprising. There are additional bookshelves in the central wing on the ground floor on the female side of the library and labs, so female student use spreads across the ground and first floors. The gender segregation across floors in QUML restricting males to the first floor requires additional bookshelves on that floor.

The QUML building footprint is ~10,000 m² with a 37.5% lot coverage. The useable floor area of the library of ~37,275 m² with 6,500 m² at the basement level, excluding the underground parking (~14,500 m² with parking), 10,000 m² on the ground floor, 8,000 m² on the first and second floors, and 4,775 m² on the third floor (Table 4).¹ The large floor area for labs in female portions of the library reflects the reality of the female-to-male student ratio (3-to-1) at QU. About half of the basement level is for underground parking, and more than half are storage spaces. The metric area of the ground floor plan appears well-distributed between circulation/communal areas, auditorium/halls for events, and labs. Offices and meeting rooms overwhelmingly characterise the third floor.

Table 4: Site and floor data for the QU Main Library (Source: QUST-2-CENG-2020-16).

QUML/Individual Floors	Area (m ²)	Percentage (%)
Plot	26,725	N/A
Building Footprint	10,000	37.5%
3 rd Floor	4,775	13.0%
2 nd Floor (Male Library)	8,000	21.5%
1 st Floor (Female Library)	8,000	21.5%
Ground Floor	10,000	27.0%
Basement Level (w/o parking)	6,500	17.0%
Totals	37,275	100%

Examination of the building suggests that gender segregation was not a significant consideration in the original design of the building. Male students do not have access to the main elevators and stairs in the central atrium. The entrance to the male library on the second floor occurs via a service elevator and fire exit stairs in the male portion of the ground floor. There is also an indication that the original building design over-allocated office spaces and under-allocated laboratory spaces. Over time, there have been adaptive re-uses of office spaces, a printing area, and a bookshelves area into laboratories, meeting rooms, and storage spaces. There was also a conversion of a programmed printing area on the

¹ There is ~7,000 m² of underground parking for a total floor area of 44,275 m². The basement level accounts for 16% of the total floor area, including the parking, which is consistent with the percentage allocation of the basement level in the effective floor area (37,275 m²).

ground floor into a communal space around the main entrance. Several study areas also expanded into a more extensive computer laboratory. Finally, students adaptively re-use some spaces for prayer areas, including a service staircase and storage areas. Despite these necessary adaptations, most of the building still operates per the architects' original intent.

3.3 Movement

Researchers observed the routes of a typical 100 people during the first ten minutes – or until they reached their destination, whichever came first – of their visit to QUML by picking up people as they entered ground-level access points. We calibrated the percentage of people observed based on the total entry counts over an entire weekday (7 am-5 pm) for each access point. Observers spread the movement trace fieldwork across the whole day to avoid skewing the results due to the library's temporal use. However, most movement trace observations occurred during the building's highest use, from 10 am to 3 pm. Observers counted small groups of people entering the library together as only a single movement trace. For these traces, researchers ended the observation whenever they reached vertical transition points (elevators or stairs) to limit the movement traces' representation to only the ground floor.²

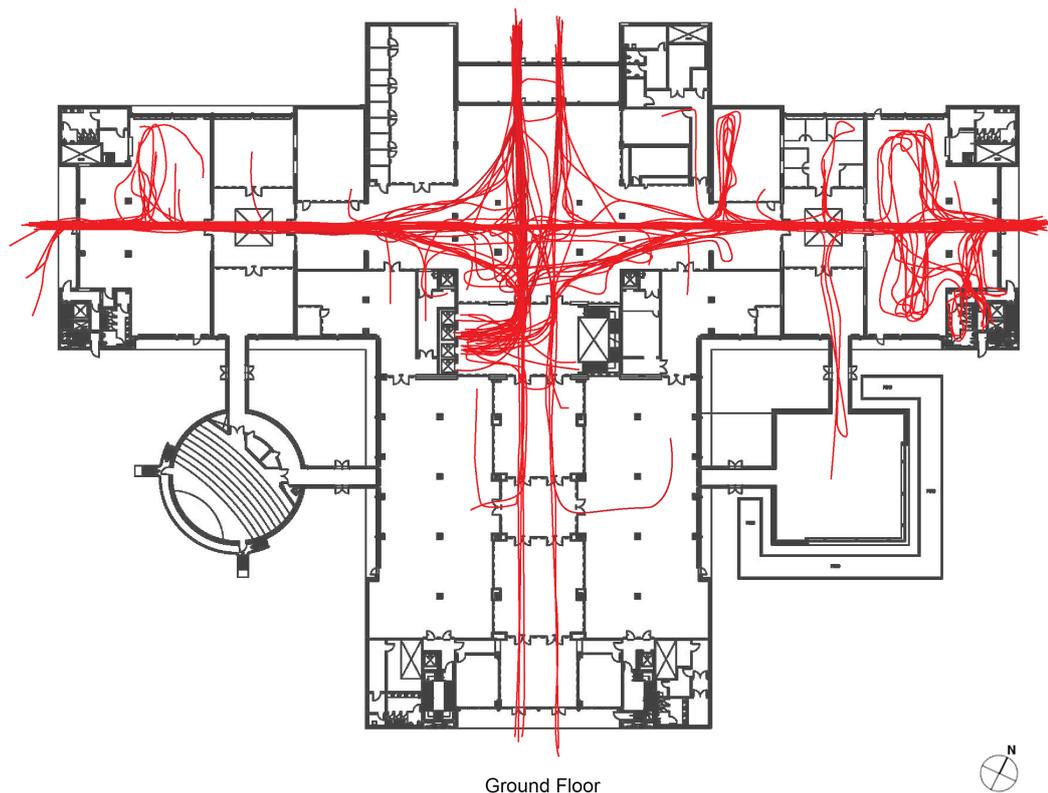


Figure 7: Movement traces of a typical 100 people during the first 10 minutes of their visit or until they reached their destination, whichever occurred first, from all access points of the ground floor in QUML during the weekday (Source: QUST-2-CENG-2020-16).

² Observers completed ninety-three (93) of these movement trace observations before the QU campus's closure in March 2020 due to the global pandemic. We finished the rest of these observations in November 2020 when there were use restrictions for QUML, including the closure of the female (west) entrance and retail outlets (Costa Coffee) in both the male and female entrance atriums. However, all missing observations were from the main (north) entrance, which simplified completing this dataset.

The movement traces demonstrate the importance of the main east-west axis and the secondary north-south cross-circulation axis in the building (Figure 7). It means the most significant density of movement in both directions occurs where these lines intersect in the central atrium of QUML. They illustrate a lot of movement accessing the elevators on the ground floor for the vertical transition to other floors, especially in the library's central part. It also demonstrates the effect of gender segregation. There is a large amount of movement internally circulating within the male atrium on the east side of the building and less in the female atrium to the west. Looking at the movement traces from each access point, people move to the central atrium elevators, female-side retail café, and cut-through from north-to-west from the main (north) entrance. The small number of entries from the restricted (south) entrance is security and service staff, mostly cutting through to the north and west to exit the building. Movement from the female (west) entrance focuses on accessing the female retail café and central atrium elevators. Finally, people move to access the male retail café, circulate within the male atrium on the east of the building, and access vertical circulation to the male library on the second floor from the male (east) entrance. However, there is significant cut-through movement from the main (east) entrance passing through the library to the north and west. This movement – and that accessing central areas of the library – is faculty, security/service staff, visitors, and female students. It appears to confirm that most people access the male (east) entrance for cut-through movement in the library. Researchers noted only a single person accessing the stairwell in the central atrium to move to other floors as everybody else utilises the elevators.

3.4 Static Use of Space

Researchers conducted static snapshots of all floors of the library, noting every person sitting, standing, interacting, and praying in most spaces during a

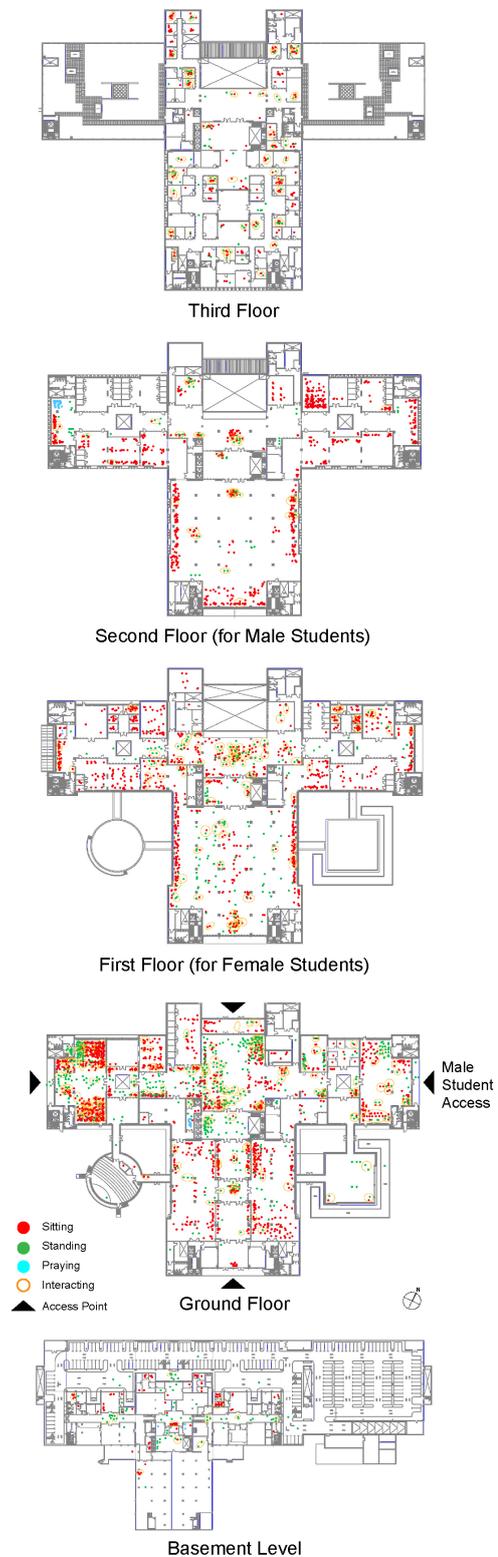


Figure 8: Static snapshots of sitting, standing, interacting, and praying on all floors of QUML during a typical weekday Source: QUST-2-CENG-2020-16).



typical weekday from 7 am to 5 pm. Our interest was the non-programmed use of the public areas in QUML (Figure 8).

Most static use in the building is sitting, unsurprising for a library. Most people sit along the edges of spaces where seating is available to avoid disrupting movement flows in the more central locations. It is apparent on all floors of the library, but especially the ground, first, and second floors housing the principal library functions, i.e., bookshelves and communal areas. There was a public event during these observations, which accounts for the high intensity/density of standing people on the central atrium's eastern wall near the main entrance.

Non-programmed static space use involving standing and interacting in the building occurs 1) adjacent to the main movement flows and 2) in public areas where seating is available (Hillier et al., 1995). It leads to a higher concentration of user interaction in the main atrium, central circulation spaces, and the east (female), central (main), and west (male) atriums. Conversely, fewer interactions occur in the southern part of the building due to the programmed functions of these areas as bookshelves, reading, and quiet areas. Small group interactions are minimal at the bookshelves, considering the expected etiquette for behaviour in a library. Some whispering interaction occurs around the edges of the spaces to avoid disrupting other users.

The ground floor is the most active for all types of static use, especially in the main atrium and the lounges associated with the retail coffee shops on the male and female sides of the building. The female students' café and lounge possess more intensity/density of use than the male (west) lounge and café over the entire day. There is a clear difference between the intensity/density of static use on the first (female) and second (male) floors. Again, it merely reflects the female-to-male student ratio (3-to-1) at QU. The lower density/intensity of use in the library's male sections does not seem to affect the frequency of use for sitting, as people are regularly occupying available seating. Because of this, people occupy the seating along the perimeter of all bookshelves most of the time. There are significantly fewer standing people in the male sections of the library compared to the female areas. It seems clear that most students come to QUML for one purpose, i.e., studying. Still, the library spaces also provide female students with additional opportunities for socialization, especially on the ground floor. The densest static interactions occur on the first and second floors in the reception area, i.e., book borrowing and group study areas. The density of people praying makes the prayer areas readily apparent in the library, whether programmed or adaptively re-use spaces. The third floor's circulation spaces are less dense for static use (mostly restricted to standing in the central corridor). Most interactive standing at the basement level also occurs in the central corridor. Still, the third-floor offices/meeting areas and basement level rooms are well-used for their programmed purpose. Overall, the snapshot observations demonstrate the effective use of all library spaces for stationary use, suggesting the library is a well-functioning built environment for studying and socialization.



Table 5: Convex mapping data for QUML (Source: QUST-2-CENG-2020-16).

QUML	Convex #	Percentage (%)	Area (m ²)	Avg. Convex Area (m ²)
3 rd Floor	195	21.5%	4,775	24.5
2 nd Floor (Male Library)	179	20.0%	8,000	44.5
1 st Floor (Female Library)	179	20.0%	8,000	44.5
Ground Floor	200	22.5%	10,000	50.0
Basement Level (w/o parking)	147	16.0%	6,500	44.0
Totals	900	100%	37,275	41.5

3.5 Space Syntax Analysis

Convex spaces relate to the occupation of space. A convex space is a polygon in a plan composed of points that are visible and accessible to every other point (Hanson, 1998; Major, 2018). Researchers created a convex map of all floors in the building (Figure 9, left). We did not account for the bookshelves in the convex mapping, only convex spaces defined by the built fabric. There are nine hundred (900) convex spaces in the entire building, with an average of 41.5 m² or ~6.5 m x 6.5 m if square in shape. There is a significant difference between the percentage of floor area and convexity (+65%) on the third floor. It is indicative of the more substantial convexity break-up on this floor characterised by small offices, meeting rooms, and service spaces such as restrooms for administrative functions (Table 5).

The average convex space area on the third floor is 24.5 m² (or ~5 m x 5 m on average). The degree of convex break-up of the male and female libraries on the 2nd and 1st floor is consistent (only -7.5%) with their floor area percentages, respectively. Convexity and floor area percentages on the basement level are also consistent (-6.25%). There is a slight difference between the floor area and convexity (+20%) percentages on the library's ground floor. However, this is due to service support spaces along the perimeter of the ground floor.

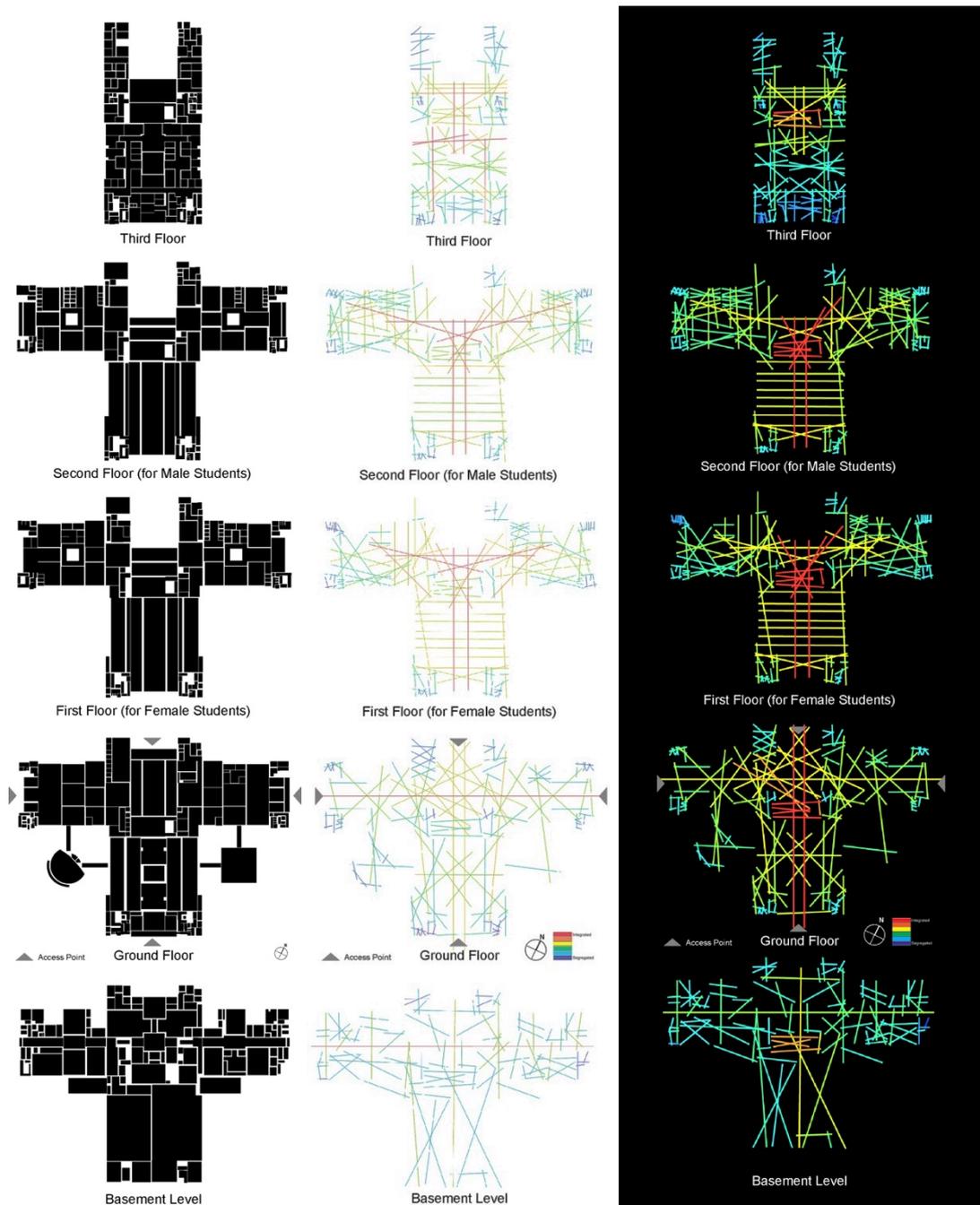


Figure 9: (left) Convex mapping, (centre) axial analysis of individual floors and (right) axial analysis of all floors in the QU Main Library (Source: QUST-2-CENG-2020-16). *Note: Basement level excluding parking areas set to same scale of the other floors.*

Researchers also constructed an axial map of all floors of QUML. The axial map is the fewest, most extended sight and access lines passing through a built environment connecting all convex spaces

(Major, 2018). Researchers can measure the configurational relationship of all lines to all others on a single floor (Figure 9, centre) and connecting all floors of a building (Figure 9, right). Axiality or linearity strongly relates to movement since people tend to take the shortest series of axial lines available from one place to another in a building (Hillier, 1996). We modelled as if all doors were open (even secured ones). Researchers also accounted for the location of bookshelves on the first and second floors in the male and female libraries, respectively.

The axial analysis of each floor indicates the importance of the east-west axis for movement circulation at the basement and ground floor levels. The east-west axis is still essential on the first (female library) and second (male library) floors. However, lightwells in the east and west wings disrupt the east-west axis for movement, but not visibility. This designed element allows for natural light from above on these two floors. In combination with the effect of the bookshelves in the south wing on both floors, it effectively shifts the core of integration away from the dominant east-west axis into a more compact one incorporating the central atrium and north-south cross-circulation routes. It is an elegant way to allow natural light without disrupting visibility (the east-west axis still reads for users but requires angular deviation around the lightwells) and emphasises the spatio-functioning of both floors as the primary library spaces for females and males. It also introduces slight segregation in the east and west wings, primarily study areas and labs. The third (administrative) floor is less integrated than the other floors except the basement, which is very segregated but for its east-west axis mediating access everywhere on that level. The third floor's smaller floor plate shifts the integration core to a shorter north-south axis and east-west cross-circulation routes, accessing south and north office wings.

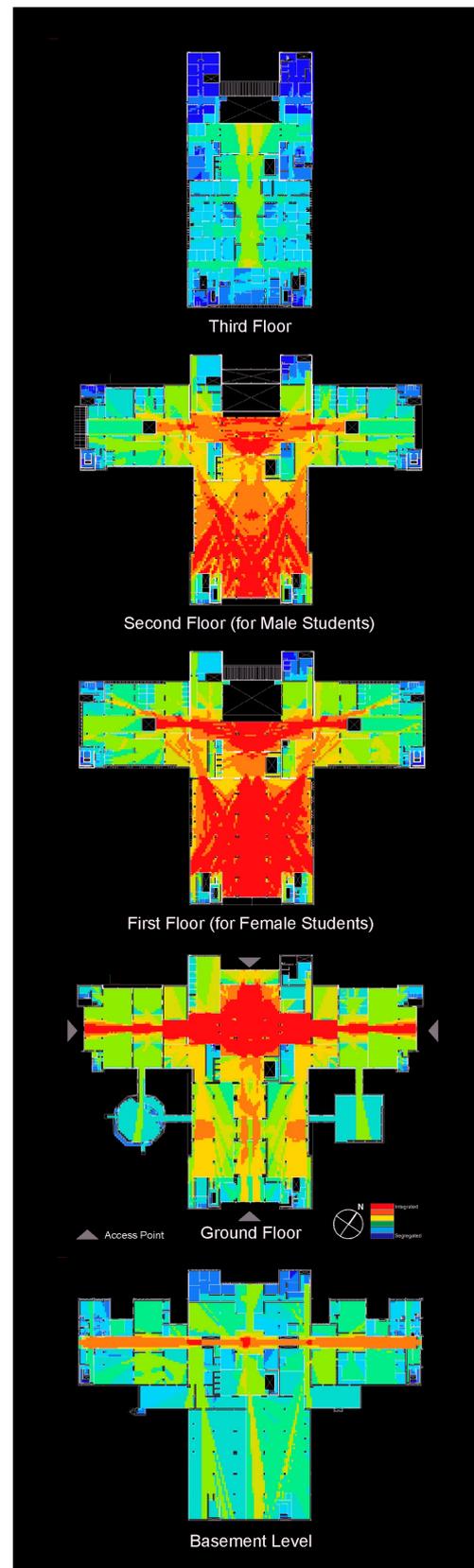


Figure 10: Pattern of integration (radius= n) in the VGA of individual floors of the QU Main Library set to the same range (Source: QUST-2-CENG-2020-16). *Note: Basement level excluding parking areas set to same scale of the other floors.*



Unsurprisingly, axial analysis of the entire building connecting all floors emphasises an integration core focused on the central elevators and staircase. It shifts the emphasis in QUML to the north-south axis on all floors. The most integrated central elevators/stairway links in the entire building are those of the ground, first, and second floors, which should be since these are the main floors for the library's principal function. Collectively, this is an elegant solution for integrating the individual floors with the entire building, generating subtle differentiations in the spatial layout at the micro- and macro-scale. All of which work well with the patterning of convexity and visibility for distinct types of spatio-functioning for individual spaces, areas, and rooms.

VGA of the individual floors bears this out (Figure 10). Like the axial analysis, this modelling treats every door (even secured ones) as open for each floor's layout. For this analysis, researchers also ignored the bookshelves on the first (female) and second (male) library floors to focus on the pattern of integrated visibility defined by the built form itself. We set a standard colour range (maximum=8.5 and minimum=1.5) for each floor in the visibility analysis to introduce a degree of comparability between floors. At the basement level, the east-west axis from the central core adjacent to the elevators/staircase represents the main view shed organizing all rooms and functions on the entire floor. On the ground floor, we see the integrative importance of the central atrium adjacent to the main (north) entrance and the east-west axis from the east (female) entrance to the west (male) entrance. On the first (female) and second (male) library floors, we see the effect of both the abbreviated east-west axis and the ample open space in the south wing of the bookshelves. These two cores on each floor link together via the central elevator/staircase atrium. The second (male) floor is a little less integrated due to the articulation of rooms at this level in the east and west wings. However, overall, the spatial differences are minor. Overall, the third floor is the most segregated floor for visibility in the building, consistent with its primary function, i.e., overseeing the library's administration and operation.

4 DISCUSSION

The intensity of studying and socializing for male and female students in the library is an interesting gender difference arising from the observations. It is not related to the building design, except in the greater space allocation for female students than male ones in the library. It closely relates to the overall student population levels at QU. Instead, it is a factor of how male and female students use the QU campus. Female students tend to stay on campus for most or all day, thereby generating a 'social experience.' Generally, male students tend to come and go as needed per their class schedules and linger less on campus. In part, it helps explain the increased interaction of female students in QUML since it represents characteristics of female students' use of most academic buildings on the campus. Interestingly, our observations of static occupation and interaction in the library identify this characteristic of our female students. However, more research on mixed-gender buildings on the QU campus may be necessary to state this definitively.



The building survey, observations of movement and space use, and space syntax modelling effectively demonstrate that the QU Main Library is well-designed for its purpose. It appears true despite the design adaptations introducing gender segregation between the male and female portions of the library. The access for male students to vertical circulation to the second (male) floors is not ideal. Still, it works, especially considering that a more elegant design solution would prove cost-prohibitive. In this sense, the gender segregation adaptation of the building only tends to reinforce the strong principles at work in the original design of the spatial layout for the QU Main Library. The architects' selection of a 'classical' cross-axis layout for the plan demonstrates the approach's effectiveness for this type of building. The design decision to place the primary vertical circulation (elevators and main staircase) near to – but not directly on – the intersection of this cross-axis was a clever choice. It enables the east-west axis to operate as the principal organizing mechanism on four floors. On the ground floor, this proves essential as the east-west axis with the north, east, and west entrances enable a degree of cut-through movement, especially for faculty and visitors. The east-west axis also strongly organises all functions at the basement level, primarily associated with building maintenance. The east-west axis remains essential on the first (female) and second (male) library floors. However, the marginal disruption of the light wells for movement, but not visibility, effectively shifts the integration core of the spatial layout to the north-south axis and ample open space for bookshelves in the south wing. It emphasises the relative compactness of the integration core on the library floors. Something similar happens on the third (administrative) floor but arises due to the small area.

Overall, this study's findings demonstrate that QUML is not only well-designed and effectively functions for its purpose. It also suggests the building as a prototypical example of best practices in library design. In a cultural setting where gender segregation is unnecessary, the building design would likely prove even more effective. The CUBE projects demonstrate the added value of POE research skills and space syntax modelling capabilities in the DAUP-CENG for built environment research to the university, other public agencies, and private industry. There will be further opportunity in the future for space syntax researchers in DAUP-CENG at QU to determine this material for even more in-depth analysis, especially about socialization of female students using the library.

5 CONCLUSION

Libraries have been a source of fascination for space syntax researchers for a long time. The paper reviewed the results of a Post-Occupancy Evaluation and space syntax modelling of the Qatar University Main Library. Given the building's strategic importance on the QU campus, the library became a case study for the ongoing CUBE Project at Qatar University in 2020. The goal of CUBE³ was to learn about the relationship between design, programming, and people's use of the library, including a cultural adaptation of its design by floor and area for gender segregation purposes. The study included observations of movement and space use, a survey of building programming, and axial, convex, and Visibility Graph Analysis mapping of the spatial layout.



The paper argued that the Qatar University Main Library is a well-designed built environment, relying on a classic cross-axis strategy to mediate between the three wings of the building. It functions efficiently for its purpose, even accommodating the awkward entry and vertical circulation sequence for male students due to gender segregation incorporated into the building program. Most male students tend to use the library primarily for study purposes, whereas female students more fully utilise the library, especially for social interaction. From one degree to another, everybody uses the library as a 'cut-through' route (especially faculty), depending on total usage by type. Finally, spatial modelling identifies the importance of the east-west main axis in the building on every floor and the north-south axis due to the loading of most vertical circulation (elevators/stairs) and metric area of the library bookshelves areas on the library floors.

ACKNOWLEDGEMENTS

Undergraduate students on the ARCT 420: Environment-Behavior Studies course in Spring 2020 in the Department of Architecture and Urban Planning, College of Engineering, at Qatar University conducted preliminary research work for this paper including: Farsana A. Abdulla Kutty, Fatima A. Ahen, Maryam Y. Al-Abdulla, Saaeda N. Al-Bader, Reem M. Al-Boinin, Aljazi M. Al-Dosari, Fatima J. AL-Hajeri, Reem N. Al-Hajri, Alreem H. Al-kaabi, Meera N. Al-khulifi, Fatma E. Al-Mohannadi, Lolwa Y. Al-Mohannadi, Najla A. Al-Mohannadi, Mai I. Al-Nasser, Moza J. Al-Neama, Maryam N. Al-Nuaimi, Wadha I. Al-Rumaihi, Manayer S. Alajami, Fatima M. AlHajri, Hessa Y. Alromaihi, Hissa S. Alsulaiti, Doha H. Elsaman, Aisha A. Jamali, Haya M. Mohammed, Maryam M. Mohd, Ghazal S. Shakerpoor, and Dana A. Sharif.

FUNDING

This research was supported in part by an internal grant of Qatar University (Grant ID: QUST-2-CENG-2020-16). The findings achieved herein are solely the responsibility of the authors.

REFERENCES

- Askarizad,R., Safari, H. (2020) "Investigating the role of semi-open spaces on the sociability of public libraries using space syntax (Case Studies: Sunrise Mountain and Desert Broom Libraries, Arizona, USA)," *Ain Shams Engineering Journal*, 11(1): 253-264, ISSN 2090-4479, <https://doi.org/10.1016/j.asej.2019.09.007>.
- Capillé, C., Psarra, S. (2016) "Disciplined informality: Assembling unprogrammed spatial practices in three public libraries in Medellín," *Journal of Space Syntax*, University College London, 6(2): 247-270
- Dalton, R.C., Hölscher, C., Eds. (2016) *Take One Building: Interdisciplinary Research Perspectives of the Seattle Central Library*. New York/London: Routledge.
- Capillé, C., Psarra, S. (2016) "Disciplined informality: Assembling unprogrammed spatial practices in three public libraries in Medellín," *The Journal of Space Syntax*, 6(2): 247-270.
- Capillé, C., Psarra, S. (2014) "Space and Planned Informality: strong and weak programme categorisation in public learning environments," *A/Z ITU Journal of the Faculty of Architecture*, 11(2) 9-29.



- Conroy, R. (2001) *Spatial navigation in immersive virtual environments*. PhD Thesis, The Bartlett School of Architecture Planning, University College London (University of London).
- Hanson, J. (1998) *Decoding Homes and Houses*. Cambridge: Cambridge University Press.
- Hillier, B., Penn, A. (1991) Visible Colleges: Structure and randomness in the place of discovery. *Science in Context*, 4(1): 23-50.
- Hillier, B. (1996) *Space is the Machine: A Configurational Theory of Architecture*. Cambridge: Cambridge University Press.
- Hillier, B., Major, M.D., Desyllas, J., Karimi, K., Campos, B., Stonor, T. (1996) *Tate Gallery, Millbank: A Study of the Existing Layout and New Masterplan Proposal*. London: Unit for Architectural Studies Report, copies available from UCL Discovery at <https://discovery.ucl.ac.uk/id/eprint/932/>.
- Koch, D. (2004) *Spatial Systems as Producers of Meaning: The Idea of Knowledge in Three Public Libraries*, Licentiate Thesis, KTH School of Architecture, Stockholm, Sweden.
- Kuliga, S., Nelligan, B., Dalton, R.C., Marchette, S., Shelton, A.L., Carlson, L., Hölscher, C. (2019) "Exploring Individual Differences and Building Complexity in Wayfinding: The Case of the Seattle Central Library," *Environment & Behavior*, 51(5): 622-665.
- Kuliga, S., Dalton, R.C., Hölscher, C. (2013) "Aesthetic and Emotional Appraisal of the Seattle Public Library and Its Relation to Spatial Configuration," *9th International Space Syntax Symposium Proceedings* (YO Kim, HT Park, KW Seo Eds.), Seoul: Sejong University, 077:1-7.
- Li, R., Klippel, A. (2014) "Wayfinding Behaviors in Complex Buildings: The Impact of Environmental Legibility and Familiarity," *Environment & Behavior*, 48(3): 482-510.
- Li, R., Klippel, A. (2012) "Wayfinding in Libraries: Can Problems Be Predicted?" *Journal of Map And Geography Libraries*, New York/London: Routledge, 8:21-8.
- Li, R., Klippel, A. (2010) "Using space syntax to understand knowledge acquisition and wayfinding in indoor environments," *9th IEEE International Conference on Cognitive Informatics (ICCI'10)*, 7-9 July 2010, Beijing, China, doi: 10.1109/COGINF.2010.5599724.
- Lazaridou, A., Psarra, S. (2017) "Spatial Navigation in Real and Virtual Multi-Level Museums," *11th International Space Syntax Symposium Proceedings*, Instituto Superior Técnico, University of Lisbon, 3-7 July 2017, 14: 1-8.
- Major, M.D., Tannous, H.O., Elsaman, D., Al-Mohannadi, L., Al-Khulifi, M., Al-Thani, S. (2020) "Complexity in the Built Environment: Wayfinding Difficulties in the Modular Design of Qatar University's Most Iconic Building," Special Issue on Defining and Debating on Smart Cities or Smart Buildings, *Smart Cities: An Integrated Framework to Measure Smart City Readiness*, 3(3), 952-977; doi:10.3390/smartcities3030048, <https://www.mdpi.com/2624-6511/3/3/48>.
- Major, M.D., Indraganti, M., Ahmed, A.M., Tannous, H.O., Al-Marri, A., Al-Noami, L., Al-Obaidan, M. (2019) 'Comfort and Use in Building Evaluation: Information Modelling and post-occupancy in the built environment,' *12th International Space Syntax Symposium Proceedings*. Beijing, China: Beijing Jiao Tong University, 8-13 July 2019, 283:1-14.
- Major, M.D. (2018) *The Syntax of City Space: American Urban Grids*. New York/London: Routledge.
- Major, M.D. (2017) "The Social Capacity of Buildings: Understanding the Implications of Design on End-users," *Engineering Capacities Building Conference*, Qatari Society of Engineers, 4 October 2017, Doha, Qatar.
- Major, M.D., Stonor, T., Penn, A. (1998) "Passengers, Pedestrians and Shoppers: Space Syntax in Design," *Passenger Terminal World*. London: April 1998, 38-42.
- Prowler, D., Vierra, S. (2021) *Whole Building Design Guide*. Washington, DC: National Institute of Building Sciences. Accessed: 1 August 2020 at <https://www.wbdg.org/building-types/libraries>.
- Psarra, S. (2007) "Tracing the modern: Space, narrative and exploration in the Museum of Modern Art, New York," *6th International Space Syntax Symposium Proceedings*. Istanbul, Turkey: Istanbul Technical University, 70.1-16.



Psarra, S. (2005) “Spatial Culture, Way-finding and the Educational Message: The Impact of Layout on the Spatial, Social and Educational Experiences of Visitors to Museums and Galleries” in *Reshaping Museum Space: Architecture, Design, Exhibitions* (McLeod, S. Ed.), New York/London: Routledge, 78-94.

Sailer K., Koutsolampros, P., Austwick, M., Varoudis, T., Hudson-Smith A. (2016) Measuring Interaction in Workplaces. *Architecture and Interaction: Human Computer Interaction in Space and Place*. New York/London: Springer International Publishing.

Sailer, K. (2015) “The dynamics and diversity of space use in the British Library,” *A|Z ITU Journal of the Faculty of Architecture*, İstanbul Teknik Üniversitesi, 12(3) November 2015, 23-39

Sato, T., Kishimoto, T., Yamada, T. (2017) “Relationship between Visitors’ Movement Path, Staying Activity and Spatial Structure in the Library as a “Third Place”: Focusing On Yamanashi Prefectural Library,” *Buildings and Architecture: 11th International Space Syntax Symposium Proceedings*, Instituto Superior Técnico, University of Lisbon, 3-7 July 2017, 26.1-26.16

Tzortzi, K. (2017) “Reading museums,” *Qualitative and Quantitative Methods in Libraries*, [S.l.], 4:2, 273-283, June 2017. ISSN 2241-1925. Available at: <http://qqml-journal.net/index.php/qqml/article/view/244>. Date accessed: 10 June 2021.

Turner, A., Doxa, M., O’Sullivan, D., Penn, A. (2001) From Isovists to Visibility Graphs: A Methodology for the Analysis of Architectural Space. *Environment and Planning B: Planning and Design*, 28(1): 103–121

Zook, J.B., Banfa, S. (2012) “Imaginative Content and Building Form in the Seattle Central Public Library,” *8th International Space Syntax Symposium Proceedings* (M Greene, J Reyes, A Castro, Eds.), Santiago de Chile: PUC, 8087: 1-24.