Supplemental Material 1: Definitions

Definitions

With regard to area measurement, there are relevant important terms that are used by the literature and need to be emphasized. These terms are defined by the healthcare design field and various organizations, such as federal or state agencies, universities, and commercial or business associations. The following section describes these terms:

Building Gross Square Footage (BGSF): The total enclosed square footage of a building measured from the surface of the outer face of the constructed walls.

Net Square Footage (NSF): The space within an individual room, measured from the inside face of the walls.

Departmental Net Square Feet (DNSF): The sum of all usable space designated to serve a department, including all of the net spaces assigned to the department or service.

Departmental Gross Square Footage (DGSF): The more common usage for departments identifies the space designated to serve the department, including all of the net space, wall thicknesses between spaces, internal corridors, and incidental space such as structural columns, water fountains, fire extinguishers, or housekeeping closets.

Non-Departmental Square Footage: A subset of building gross space that accounts for corridors and other space not attributable to a department.

Exterior Wall Thickness: That portion of the building attributable to the thickness of the surrounding walls of the building. It is a component of the building gross area. Sensitivity analysis has shown that the exterior wall should not be attributed to the contiguous department.

Miscellaneous Structure: The area in plan of unusual structural elements which should not be attributed to a department, as in the case of earthquake bracing.

The following definitions are common in commercial and non-medical construction. They are particularly useful for the purpose of rental agreements. Hospitals may find instances where the use of these terms is expected.

Gross Building Area: The sum of all floor areas of a building measured between outside faces of the building including all horizontal and vertical circulation, service, and mechanical areas (WSU, 2007; ANSI/BOMA, 1996; FDE, 2012; ME, 2012). Any architectural features that projects out of a building, such as pilasters, awnings, cornices, buttresses, etc., are excluded from the measurements (WSU, 2007; FDE, 2012; ME, 2012).

Net Building Area: It is the sum of all areas enclosed by the walls measured within the inside faces (FDE, 2012; VDE, 2013). The sum of all usable area that is either assigned to or currently available for assigning to occupants, or a function or use was defined as *net usable square feet* (WSU, 2007). ME (2012) defined a similar term as room or module area, which is the area measured within the inside surface of a space such as a room. Similarly, TCFMD (2009) used the term *Tenant Area* as the sum of all areas assigned to a specific use excluding any circulation, service or architectural projection area.

Assignable Building Area: Is the total area assigned to or can be assigned to occupants or to a specific function (WSU, 2007; FDE, 2012). It does not include the wall thickness, but includes any circulation space that is part of the space or a suite of spaces. However, according to FDE (2012), interior and exterior circulation, restrooms, mechanical and structural areas are excluded from the total assignable area.

Non-assignable Building Area: Contrary to the assignable building area, the sum of all areas that is not assigned to or is not available to be assigned to occupants or to a specific function or use is known as *non-assignable building area* (WSU, 2007; FDE, 2012). The sum of assignable and non-assignable areas provides the net building area (WSU, 2007; FDE, 2012). When the total net building area is deducted from the total gross building area the remainder is called the total structural area (WSU, 2007; FDE, 2012).

Supplemental Material 2: Design Approaches to Architectural Programming

There are other design approaches that can be used in architectural programming of healthcare facilities, including the integration of evidence-based design criteria and approaches, affordance-based design, user involvement, and Six Sigma and Lean analysis. Ulrich (2001) suggested significant costs and quality related benefits can be achieved if "evidence-informed design goals" are added to architectural programming early in pre-design phases. Maier et al. (2009) discussed the integration of "affordance-based design," (the design of a building based on occupants' needs and environment) into architectural programming, as a vital analytical process to attain "quality architecture."

In space management of hospital facilities, Vos et al. (2007) discussed a Dutch hospital that centralized the internal waiting areas to facilitate the free flow of occupants and goods in a new "twenty-first century airport" concept, creating an efficient hospital space use and management. Rhodes (1992) conducted a study to develop and validate a method for assessing the space utilization of Department of Defense (DoD) medical facilities, using Computer-Aided Design (CAD). His study compared the authorized space area (amount of space as per DoD Medical Space Planning Criteria) with the actual space area and developed a space management tool for medical facilities commanders to use. Similarly, Minior et al. (2004) studied space management in urban hospital campuses qualitatively and quantitatively. In the qualitative analysis, they analyzed space, budget, and people, while quantitatively they analyzed the net assignable area with total cost and full-time equivalents to provide a platform for space utilization density calculation. They finally concluded that underutilized and over-utilized spaces need to be identified to create a balanced space management.

Supplemental Material 3: Standards and Guidelines for Measuring Building Areas

The standards or guidelines for measuring building areas are important for facility and property managers, especially when dealing with facility extension, sale, lease, or renovation (Tracy, 2010). A study conducted by Allison and Hamilton (2008) concluded that a standard method of measuring the area of healthcare facilities is still lacking. The American Institute of Architects first published document AIA D101 entitled *Methods of Calculating Areas and Volumes of Buildings* in 1995 (AIA, 1995). They further suggested developing standards in conformation with the AIA D101-95. There are two organizations involved in developing area measurement standards for built facilities (GSA, 2013): the first organization is the Building Owners and Managers Association (BOMA) that initially published the *Standard Method of Measuring Floor Area in Office Buildings* (ANSI/BOMA, 1996; Tracy, 2010; Horsley, 2008; WIDOA, 2011). These standards were appropriate for office buildings only, and so it could not have been utilized for area measurements in other types of buildings such as higher education, healthcare, and retail. Since then, BOMA has published measurement standards for other types of buildings in association with the American National Standards Institute (ANSI) (Tracy, 2010; Horsley, 2008; WIDOA, 2011).

The second organization is the International Facility Management Association (IFMA), which in association with the American Society for Testing and Materials (ASTM) proposed area measurement guidelines. These standards are published as The ASTM *Standard Classification for Building Floor Area Measurements for Facility Management* (Horsley, 2008). Recently, BOMA and IFMA collectively published *A Unified Approach to Measuring Office Space* that is a document providing common floor area definitions and related standards (Horsley, 2008; WIDOA, 2011). Another set of standards was published by the Canadian Standards Association specifically for healthcare facilities. The standard entitled *Area Measurement for Health Care Facilities* was published in March 2002 (CSA, 2002).

Consistent use of definitions is important for the development of accurate and comparable listings of space requirements. Definitions are provided in Supplemental Material 1.

The commercial standards mentioned above have been utilized in measuring space areas in a standard manner by a wide range of users such as tenants, building owners, property managers, facility consultants, and asset managers (Hensey and Thatcher, 2009). According to Hensey and Thatcher (2009), these standards are being used in space utilization assessments and space management in addition to portfolio marketing by tenants. They are also utilized as a starting point or a basis for developing standards for other building types within and across the United States. For instance, the BOMA method of area measurement for office buildings was utilized as a basis for deriving space measurement standards for the Saskatchewan Ministry of Education in Canada. The purpose of these standards was to standardize the process of area measurement in various school and non-school buildings (SME, 2013). The BOMA standards were also used as a starting point by the General Service Administration (GSA) Public Buildings Service in developing the National Business Space Assignment Policy (NBSAP) (GSA, 2013). Interestingly, using BOMA standards, Deru and Torcellini (2005) developed standard area measurement definitions and metrics for building geometry, to be used for building energy modeling. The purpose was to standardize the buildings' geometric modeling and area measurement definitions.

GSA (2013) surveyed a range of space measurement standards to find out current trends and practices in the field. According to GSA (2013), the federal government is shifting its stand from using strict space standards to developing space need based on organizational goals. Carter and Zhang (2007) referred to the BOMA, IFMA, and ASHRAE area measurement standards for defining key space area terms for evaluating the indoor Volatile Organic Compound (VOC) concentration in a standard manner.

Portions of North America work with the metric system of measurement rather than the imperial system. Please bear in mind that the area calculation methodology is the same for square meters as it is for square feet. Thus, NM^2 is the same calculation as NSF, DGM^2 is the same calculation as DGSF, and so forth. This document is written in the language of square feet but one can easily make the translation to square meters.

The current study calculates all of the area in the measured hospital projects. Governmental organizations, such as the U.S. Veteran’s Administration or the U.S. Department of Defense, find area calculation to be critical in preparing project budgets and designs (Rhodes, 1992).

Supplemental Material 4: Locations of Studied Projects

Figure S1: Maps of Canadian Provinces and U.S. States from which projects were collected and measured

- States/provinces from which one project was measured and included in this study
- States/provinces from which two or more projects were measured and included in this study

Supplemental Material 5: Areas Measured

Table S1 indicates the number of sites which include the departments listed and measured. It also provides the total square footage measured across all the departments in each category.

Table S1: Distribution of areas measured ("n" stands for the number of projects in which each unit/department was measured)

Space Category		n	Area Measured (SF)	=>25
Departmental Gross Square Footage (DGSF)				
Patient Units				
	Acute Care Unit	36	2,582,174	+
	Intensive Care Unit	31	662,630	+
	Intermediate Care Unit	7	107,510	
	Psychiatric Care	4	93,199	
	Ambulatory Care	2	31,408	
	Obstetrics	29	1,001,033	+
	Sub-Total Patient Units		4,477,954	
Procedure Departments				
	Emergency Department	34	682,086	+
	Dialysis	16	44,081	
	Endoscopy	18	50,274	
	IV Therapy	5	7,143	
	PACU	28	122,802	+
	Pre-Op. Care/Prep/Recovery Unit	30	273,795	+
	Rehabilitation	25	135,791	+
	Respiratory Therapy	15	27,348	
	Surgery	35	749,962	+
	Sub-Total Procedure Depts.		2,093,282	
Diagnostic Departments				
	Cardiac Cath.	19	123,710	
	Cardiology	12	71,367	
	Imaging	35	679,619	+
	Neurodiagnostics	8	32,060	
	Pathology	35	220,237	+
	Pre-Admission Testing	10	24,131	
	Pulmonary Function	4	6,535	
	Urodynamics	2	2,049	
	Sub-Total Diagnostic Depts.		1,159,707	
Centers of Excellence				
	Cancer Center	6	71,269	
	Cardiac/Heart Center	1	4,739	
	Clinics	7	308,389	
	Sub-Total Centers of Excellence		384,397	

Support Services				
	Bio Medical Engineering	25	27,784	
	Building Maintenance	20	44,930	
	Central Sterile Processing	33	182,851	
	Engineering/Facility Management	11	32,106	
	Environmental Services	19	28,602	
	Food & Nutrition	35	450,577	
	Linen	17	28,646	
	Materials Management	35	202,360	
	Pharmacy	35	172,328	
	Security	18	10,818	
	Staff Support	24	72,123	
	Sub-Total Support Services		1,253,125	
Administrative & Public				
	Administration/Medical Staff	36	298,963	
	Business Offices	6	14,402	
	Chapel	33	40,717	
	Conference/Education	30	110,057	
	Gift Shop	27	27,923	
	Information Technology	28	65,014	
	Medical Records	22	53,164	
	On Call	19	32,049	
	Patient Admitting	11	29,900	
	Public Spaces	36	337,070	
	Registration	16	34,282	
	Resource Center	5	2,492	
	Retail	9	18,077	
	Volunteer Services	16	11,536	
	Sub-Total Administrative & Public		1,075,644	
Sub-Total Area			10,444,109	
	Shell Space	24	750,838	
Total DGSF		**36**	**11,194,946**	
Building Gross Square Footage (BGSF)				
	Mechanical	36	895,078	+
	Electrical	36	219,784	+
	Communication Distribution	36	75,185	+
	Non-Departmental Corridors	36	1,291,205	+
	Stairs	36	282,228	+
	Vertical Transport	35	303,918	+
	Misc. Structures	1	74	
	Exterior Covered Areas	6	10,295	
	Exterior Wall Thickness	36	496,487	+
Total BGSF		**36**	**3,574,255**	

Building Total (DGSF + BGSF)	**36**	**14,769,201**
Other Areas Not Included in Calculations		
Faculty Offices	1	1,717
Central Plant	13	175,170
Canopies	24	207,036
Parking	3	18,741
Sub-Total Other Areas		**402,665**
Grand Total Measured	**36**	**15,171,866**

Supplemental Material 6: Descriptive Statistics of Measurements for Selected Departments

Tables S2-S5 and Figures S2-S4 provide ranges of measurements for selected departments and building gross elements. Readers are cautioned to use ranges rather than means for planning purposes.

Table S2 shows the minimum, maximum, and selected percentiles (10th, 25th, 50th, 75th, and 90th) of actual measurements for departments with 25 measurements or more, while Table S3 shows the same data for all BGSF functions with 25 measurements or more.

Table S2: Minimum, maximum, and selected percentiles of actual measurements for departments with at least 25 data points

Department	Min.	10 per.	25 per.	50 per.	75 per.	90 per.	Max.
Acute Care Unit	1.39	1.45	1.49	1.52	1.56	1.62	1.71
Intensive Care Unit	1.36	1.42	1.46	1.50	1.55	1.62	1.65
Obstetrics	1.36	1.39	1.44	1.46	1.52	1.55	1.65
Emergency Department	1.24	1.46	1.52	1.61	1.70	1.76	1.83
PACU	1.12	1.30	1.61	1.71	1.78	1.99	2.19
Pre-Op. Care/Prep/Rec.	1.07	1.15	1.56	1.74	1.82	1.87	1.90
Rehabilitation	1.05	1.08	1.09	1.20	1.37	1.47	1.68
Surgery	1.25	1.36	1.41	1.50	1.59	1.65	1.90
Imaging	1.26	1.34	1.38	1.47	1.57	1.66	1.73
Pathology	1.05	1.06	1.10	1.16	1.24	1.31	1.39
DGSF:NSF	1.19	1.29	1.34	1.38	1.43	1.46	1.47

Table S3: Minimum, maximum, and selected percentiles of actual BGSF function measurements for departments with at least 25 data points

BGSF Functions	Min.	10 per.	25 per.	50 per.	75 per.	90 per.	Max.
Mechanical	0.49%	1.76%	3.86%	6.55%	9.07%	12.99%	19.79%
Electrical	0.54%	0.70%	1.20%	1.83%	2.30%	2.86%	3.54%
Communication Dist.	0.01%	0.31%	0.42%	0.65%	0.82%	1.09%	1.41%
Non-Dept. Corridors	6.60%	8.83%	10.50%	11.98%	13.69%	16.66%	18.75%
Stairs	0.20%	1.31%	1.99%	2.40%	2.91%	3.72%	4.63%
Vertical Transport	0.39%	1.01%	1.30%	1.92%	2.95%	3.57%	7.69%
Exterior Wall Thickness	2.63%	3.60%	3.98%	4.37%	4.89%	5.45%	7.18%
BGSF:DGSF	1.18	1.22	1.27	1.31	1.35	1.39	1.52

Normality of data distribution cannot be assumed automatically; instead, there are several statistical tests that can be performed to test this hypothesis. The most powerful test of normal distribution of data is known as the Shapiro-Wilk normality test. Here, the null hypothesis is that data is distributed normally, and only in cases where a certain level of significance is found to reject this hypothesis (known as p-value threshold), then we can reject the null hypothesis and conclude that data is not distributed normally. Table 4 shows the results of the Shapiro-Wilk test conducted on DGSF:NSF ratios in departments with at least 25 data points measured. This hypothesis test assumes a p-value of .05, which means that only in cases where the p-value is lower than .05, the null hypothesis (of normal distribution of the data) may be rejected. Based on this analysis, one may conclude that all departments/units show a normal distribution of their DGSF:NSF ratios, except from “Pre-Op. Care/Prep/Recovery Unit,” “Rehabilitation,” and “Pathology”. Table 5 shows a similar analysis conducted on all BGSF functions with at least 25 data points measured. Based on the results of these tests, one may conclude that all BGSF functions show a normal distribution of their BGSF:DGSF ratios, except from “Vertical Transport.”

Table S4: Shapiro-Wilk normality test for departments with at least 25 data points at α=.05 (H0 – Data is distributed normally)

Department	N	Mean	S.D.	W-value	Threshold (p=0.05)	p-value	Test result
Acute Care Unit	36	1.5328	0.0743	.9401	.935	>.05	Retain H0
Intensive Care Unit	31	1.5070	0.0735	.9730	.929	>.05	Retain H0
Obstetrics	29	1.4706	0.0648	.9528	.926	>.05	Retain H0
Emergency Department	34	1.6033	0.1309	.9730	.933	>.05	Retain H0
PACU	28	1.6867	0.2534	.9376	.924	>.05	Retain H0
Pre-Op. Care/Prep/Rec.	**30**	**1.6414**	**0.2492**	**.8301**	**.927**	**<.01**	**Reject H0**
Rehabilitation	**25**	**1.2403**	**0.1714**	**.8824**	**.918**	**<.01**	**Reject H0**
Surgery	35	1.5060	0.1425	.9680	.934	>.05	Retain H0
Imaging	35	1.4843	0.1254	.9618	.934	>.05	Retain H0
Pathology	**35**	**1.1741**	**0.0970**	**.9262**	**.934**	**<.05**	**Reject H0**
DGSF:NSF	36	1.3723	0.0694	.9356	.935	>.05	Retain H0

Table S5: Shapiro-Wilk normality test for BGSF functions with at least 25 data points at α=.05 (H0 – Data is distributed normally)

BGSF Functions	N	Mean	S.D.	W-value	Threshold (p=0.05)	p-value	Test result
Mechanical	36	7.01%	4.43%	.9503	.935	>.05	Retain H0
Electrical	36	1.80%	0.81%	.9557	.935	>.05	Retain H0
Communication Dist.	36	0.64%	0.31%	.9846	.935	>.05	Retain H0
Non-Dept. Corridors	36	12.28%	2.85%	.9740	.935	>.05	Retain H0
Stairs	36	2.50%	0.94%	.9804	.935	>.05	Retain H0
Vertical Transport	**35**	**2.28%**	**1.46%**	**.8534**	**.934**	**<.01**	**Reject H0**
Exterior Wall Thickness	36	4.45%	0.87%	.9657	.935	>.05	Retain H0
BGSF:DGSF	36	1.3103	0.0709	.9671	.935	>.05	Retain H0

Figures S2 through S4 show the distribution of the Departmental Gross SF to Departmental Net SF ratios in three selected units: Acute Care, Emergency Department, and the Surgery Department. All cases include eight bar ranges, where the bars located closest to the center represent the number of measurements that fall within one standard deviation above or below the mean value; the bars located further to the left or right of each figure show the number of measurements that fall outside the range of minus or plus three standard deviations from the mean value, respectively.

Figure S2: Frequency of DGSF:NSF ratios for Acute Care Units (n=36)

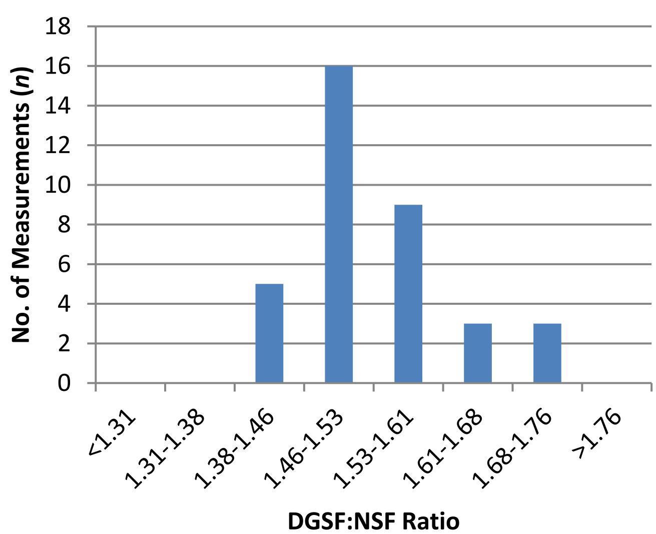


Figure S3: Frequency of DGSF:NSF ratios for Emergency Departments (n=34)

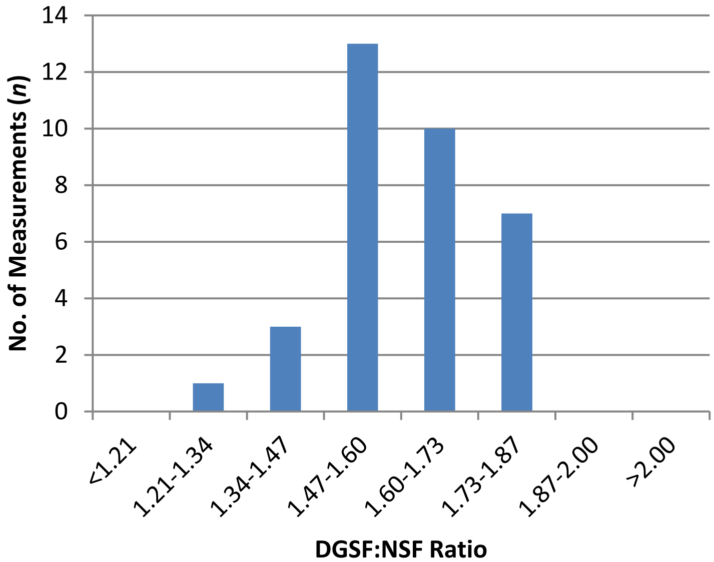
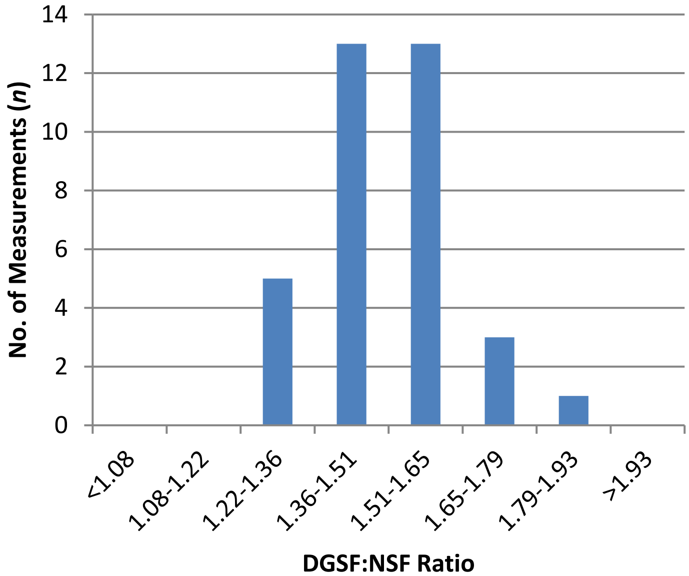


Figure S4: Frequency of DGSF:NSF ratios for Surgery Departments (n=35)



Supplemental Material 7: T-tests for Small vs. Community Hospitals, Rooftops, Courtyards, and Ratings

Table S6: Two-tailed T-Test for the differences between "Small" and "Community" hospitals at α=.05 (H0 – No difference between the two populations)

Populations to Compare	t-value	df	p-value	Test Result
Small-Community (DGSF:NSF)	**2.3247**	**9**	**.0451**	**Reject H0**
Small-Community (BGSF:DGSF)	0.8313	9	.4273	Retain H0

Table S7: Two-tailed T-Test for the differences between "Enclosed" and "Roof Top" mechanical systems, by BGSF functions, at α=.05 (H0 – No difference between the two populations)

BGSF Function	Enclosed		Roof Top		t-value	df	p-value	Test Result
	Avg.	S.D.	Avg.	S.D.				
Mechanical	**9.07%**	**4.04%**	**3.36%**	**2.18%**	**5.5125**	**12**	**.0001**	**Reject H0**
Electrical	1.84%	0.87%	1.74%	0.74%	0.3782	12	.7119	Retain H0
Communication Dist.	**0.73%**	**0.28%**	**0.49%**	**0.30%**	**2.3851**	**12**	**.0344**	**Reject H0**

Non-Dept. Corridors	12.29%	2.87%	12.26%	2.93%	0.0229	12	.9821	Retain H0
Stairs	2.70%	1.00%	2.14%	0.72%	1.9732	12	.0720	Retain H0
Vertical Transport	**2.68%**	**1.59%**	**1.59%**	**0.90%**	**2.5873**	**12**	**.0238**	**Reject H0**
Exterior Wall Thickness	**4.74%**	**0.82%**	**3.93%**	**0.73%**	**3.0530**	**12**	**.0100**	**Reject H0**
DGSF:NSF	1.38	0.07	1.35	0.07	1.3635	12	.1978	Retain H0
BGSF:DGSF	**1.34**	**0.06**	**1.26**	**0.05**	**4.6199**	**12**	**.0006**	**Reject H0**

Table S8: Two-tailed T-Test for the differences between “With Courtyard” and “Without Courtyard”, by BGSF functions, at α=.05 (H0 – No difference between the two populations)

BGSF Function	**With Courtyard**		**Without Courtyard**		**t-value**	**df**	**p-value**	**Test Result**
	Avg.	**S.D.**	**Avg.**	**S.D.**				
Mechanical	7.00%	4.34%	7.01%	4.59%	0.0102	13	.9920	Retain H0
Electrical	1.90%	1.02%	1.74%	0.67%	0.5249	13	.6085	Retain H0

Communication Dist.	0.61%	0.22 %	0.66%	0.36%	0.4780	1 3	.6406	Retain H0
Non-Dept. Corridors	12.25 %	2.77 %	12.30%	2.96%	0.0490	1 3	.9617	Retain H0
Stairs	2.62%	0.68 %	2.42%	1.08%	0.6549	1 3	.5240	Retain H0
Vertical Transport	2.07%	1.14 %	2.41%	1.66%	0.7195	1 3	.4846	Retain H0
Exterior Wall Thickness	4.51%	1.10 %	4.41%	0.71%	0.3067	1 3	.7639	Retain H0
DGSF:NSF	1.37	0.07	1.37	0.07	0.3318	1 3	.7453	Retain H0
BGSF:DGSF	1.31	0.07	1.31	0.07	0.0486	1 3	.9620	Retain H0

Table S9: Number of projects, by rating, and their mean and S.D. area ratios

Rating Level	**No. of Projects**	**% of Total**	**DGSF:NSF**		**BGSF:DGSF**	
			Mean	**S.D.**	**Mean**	**S.D.**
A = 1-4 (Easy)	10	27.8%	1.36	0.08	1.29	0.07
B = 5-7 (Medium)	12	33.3%	1.35	0.07	1.30	0.07

C = 8-10 (Difficult)	8	22.2%	1.39	0.06	1.32	0.04
Not rated	6	16.7%				
Total	36	100.0%	1.37	0.07	1.31	0.07

Table S10: Two-tailed T-Test for the differences between various project ratings, at α=.05 (H0 – No difference between the populations)

Populations to Compare	**t-value**	**df**	**p-value**	**Test Result**
A-B (DGSF:NSF)	0.3330	9	.7468	Retain H0
A-B (BGSF:DGSF)	0.4633	9	.6541	Retain H0
A-C (DGSF:NSF)	0.9892	7	.3555	Retain H0
A-C (BGSF:DGSF)	1.1203	7	.2995	Retain H0
B-C (DGSF:NSF)	1.3988	7	.2046	Retain H0
B-C (BGSF:DGSF)	0.6537	7	.5342	Retain H0

Table S9 presents the mean and S.D. values for the area ratios for each category of rating. Table S10 presents the results of a t-test analysis that compares these ratios between the three categories of rating.