Residential Interior Occupant Health Criteria Review and Assessment in Holland, Michigan

Morna Hallsaxton, and Jon Bryan Burley

Abstract**—**Investigators are interested in the environmental quality of interior spaces. At present, scholars have developed limited metrics in assessing interior environments. For our study, we examined the environmental quality of residential environments in Holland, Michigan. We examined houses in four separate age groups; 1900 to 1930, 1940 to 1965, 1965 to 1985, and 1989 to 2050. In addition, we examined the age groups based upon size of the house: under 111.48 m^2 (1200 sq. ft.) and over 185.8 m^2 (2000 sq. ft) for a total of eight treatments. Three houses were measured in each treatment. Fourteen variables were measured in each structure. Friedman's analysis of variance was employed to assess the statistical difference between the treatments. The results revealed that homes built from 1965 to 1985 with over 185.8 m^2 were healthier ($p<0.05$). The least healthy homes were those aged from 1903 to 1940, and 1940 to 1965 and smaller than 111.48 m^2. We encourage investigators to assess other types of residential environments.

Keywords**—** design history, environmental design, interior design, sustainable design.

I. Introduction

IT It has been documented that humans can spend as much as 90% of their time inside [1]. With so much time spent inside, the importance of healthy interiors is becoming more obvious. The interactions humans have with their environments are obtained by interaction with the five senses: seeing, hearing, smelling, touching, and tasting [1]. When an individual communicates with their sensory information, the environmental interpretation then goes through their nervous system to become a mental awareness.

Though most investigations concerning health care and office environments have been in the form of case studies, information addressing residential environments is even less documented. The US Green Build Council (GBC) has developed a standard for the construction process of sustainable buildings. Leadership in Energy and Environmental Design (LEED) has determined specific points to reach different levels of sustainable construction. This process encourages builders, owners and other participating individuals to learn more about how to construct with efficient cost, energy, water, material & site preservation.

Interior physical environment can have an influence upon the health of an individual, including emotional, social and physical influences. Other statistical evidence suggests that an individual's perception of a healthy space is critical in achieving a balance between the individual's physical balance and holistic attitude [2]. Maslow's behavioral model has designated certain levels of behavior and development to better health starting with physical, to belonging, safety, self-confidence, and then self-actualization [1]. Evidence has suggested the visual influence of an interior environment can effect an individual's level of stress, mental fatigue, and recovery from physical illness [3] [4].

Visual aesthetics of an interior environment affect human well-being. Kaplan & Kaplan were able to recognize the recovery of mental fatigue by the elements within the spaces [5]. Some of the elements used for this consideration are: light, sound, indoor air quality, water purity, temperature, & humidity [6]. Individual control for space, as well as privacy has been recognized to decrease mental stress [4].

Investigators are beginning to quantitatively assess numerous difference and similarities across an array of variables for interior environments. In 2009, Lee and Guerin complied a survey based assessment assess air quality, lighting, and thermal quality in office spaces [7 and 8]. They determined that employees in office environments with tall cubicle walls encountered lighting problems. In addition, the 5 treatments in their study often encountered similar conditions. Other notable investigations include efforts by Pejtersen et al., Danielsson and Bodin, Lee and Ki, and Nasrollahi et al., [9, 10, 11 and 12]. Most of these investigations rely on survey information and address the office environment. Other investigators have explored approaches to assess exterior environments with a series of independent variables and to assess a design via a concept [13, 14, & 15]. In contrast, we were interested in residential environments and variables measure in the structure. For example investigators have examined energy use in residential settings [16, 17, 18, 19]. We were interested in measuring the wellness of interior environments for a local setting in Michigan. Finally were also interested in assessing residential structures according to age and size.

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II. Study area nad Methodology

This research was conducted with a list of fourteen variables involving the four senses (sound, touch, sight, and smell) that were employed for the implementation and evaluation of interior residential environments. This list of variables was designed for one investigator to collect data. Explicit details concerning the measurement and calculations for the 14 variables can be found by Hallsaxton [20]. Two of the variables were related to sound. One of the variables was related to touch. Three of the variables were related to sight, light, and visually quality. Eight of the variables were associated with smell, making the total number of variables 14. The is nothing special about these 14 variables. They were simply 14 variables that could be measured in the residential setting. Typically it takes numerous studies to validate variables, assess the covariance of variables, and to determine which variables and combinations of variables best represent an accurate picture of spatial quality.

In this study, four separate age groups in Holland, Michigan were examined: 1900 to 1930 (Figure 1), 1940 to 1965 (Figure 2), 1965 to 1985 (Figure 3), and 1989 to 2005 (Figure 4). In addition, two size groups were under 111.48 m^2 (1200 sq. ft.) and over 185.8 m^2 (2000 sq. ft.) for each age class were selected. This made a total of eight treatments. Three homes were measured for each treatment, resulting in 24 homes being measured. The collected data was analyzed with Friedman's Two-way Analysis of Variance, nonparametric statistical data [21]. The advantage of this test is that it is a distribution free statistical test that can examine all treatments to determine if any one treatment is actually better across all the variables. In addition, there is nothing special about these two treatments: floor sizes and the year build. Although we were interested in examining two sizes of homes across several ages of homes. In the future, investigators may find a better category of ages and home size. There are many types of variables that one may consider. However given the low number of studies in this field, there is much to explore and consider.

For this experiment, the null hypothesis H0 : ø1 = ø2 = ø3, means no treatment is significantly different than another. To demonstrate the hypothesis false, at least two of the treatments, or sum of the ranks (k) would not be statistically equal. If the null hypothesis is rejected, then the Friedman's Multiple Comparison Test is employed to determine which treatments were specifically are different [21].

Figure 1. An image of an home in West Michigan built between 1900 and 1925. (copyright © 2010 Morna Hallsaxton all rights reserved, used by permission)

Figure 2. An image of a small home in West Michigan built in the 1950s. (copyright © 2010 Morna Hallsaxton all rights reserved, used by permission)

Figure 3. A photograph of a large home built in between the 1960s and 1985. (copyright © 2010 Morna Hallsaxton all rights reserved, used by permission)

Figure 4. An image of a home built in the 1990s. (copyright © 2010 Morna Hallsaxton all rights reserved, used by permission)

III. Results

When examined individually the results can be perplexing. However, the Friedman's Two-way Analysis of Variance helps to clarify the relationships across all variables and all treatments. Before examining this test, the results of each variable can be inspected separately (presented in Tables 1 and 2). First, the large homes over 185.8 square meters built between 1965 and 1985 had the lowest noise levels with the small homes built between 1901 and 1030 had the highest levels of noise. Related to touch, the large and small homes built between 1989 and 2005 had the best touch scores and the small homes built from 1901 to 1930 had the worst score. Older homes scored more poorly in relationship to visual/light variables in comparison to newer homes. For the smell related variables, the results were very mixed, with older, newer, larger, and smaller homes containing both high and low scores. The Friedman's Two-way Analysis of Variance can assist to reveal the difference in this complex situation.

The results of the Friedman's Two-way Analysis of Variance test indicated that the null hypothesis can be rejected ($p<0.05$) and that the alternate hypothesis "that at least one treatment is significantly different than the other treatments" can be accepted. Tables 1 and 2 presents the results from the data and the tabulation of the basic information necessary to complete the statistical test. In Tables 1 and 2, the totals at the end of both tables indicate the overall collection of data from treatment results. Homes between the ages of 1965 to1985 over 185.8 square meters having the smallest numbers are evident as having the healthiest interior environments. The worse ranked home was smaller than 111.48 m^2 (1200 ft^2) and between the ages of 1901 to 1930 (having the largest numbers). Following the table, the calculations to determine the probability that at least one treatment is significantly different are presented. Table 3 illustrates the results of the Multiple Comparison Tests.

To determine X_r^2, the equation with fourteen blocks (b), and eight treatments (k) equation 1 is applied.

$$X_r^{2} = [[12/bk(k+1)]*[\sum_{J=1}^{k}(\sum Rj)^2]] - [3b(k+1)] \quad (1)$$

$$X_r^{2} = 24.036$$

Equation 2 illustrated below is the final adjustment for Chi-Square based upon ties in the data set.

$$\chi_r^2 = 1-(42/(14*8)(14-1) \quad (2)$$

$$X_r^2 = 0.97115$$

Equation 3 then represents the adjustment for the calculated Chi-square.

$$X_r^2 = 24.036/0.97115 = 24.7496 \quad (3)$$

When considering the rejection of Ho where k -1 = 7 degrees of freedom, the reliability between the sum of the squares being as large as 24.7496 with $p \leq 0.01$ indicates that Ho can be rejected. Where 0.05 at is 14.067 at (k-1) = 7 degrees of freedom, and 0.01 at df = 7 is 18.475. Since the calculated Chi-square of 24.7496 is greater than 18.475, this statistical test indicates a significant difference in at least one of the treatments evaluated.

When rejecting the Ho from Friedman analysis one can continue and conduct the Multiple Comparison Test to determine which treatments significantly vary. One starts by searching for the value of z to evaluate the comparison between all the treatment results, illustrated in equation 4. An alpha of 0.05 has been chosen.

z = / k(k-1) (4)

= 0.05/8*7

= 0.00089

= 0.001

Where a z-score for 0.5 minus 0.001 is the value of – a z-score of 3.08 in a z-score table. This z-score can be used in an equation (5) to compute the value that two treatments must be apart in order to be significantly different at the alpha value chosen. The absolute value between two treatments is the difference of interest.

Now knowing the value of z, the number can be used to insert into the equation for multiple comparison to determine the least value needed for the differences between the treatment rank totals [21].

$z = 3.08 * [bk(k+1)/6]^{0.5}$ (5)

$= 3.08 [14*8*9/6]^{0.5}$

$= 3.08\ [168]^{0.5}$

$= 39.921$

The value 39.921 can be compared to the differences in Table 3. Absolute value differences greater than 39.921 indicated a significant difference between specific treatments ($p<0.05$). Ranks 1 is significantly better than ranks 6, 7 and 8. No other treatments are significantly different. The number one rank is the treatment aged 1965 to 1985 over 185.8 m^2. This treatment is better than homes from 1901 to 1930 and 1940 to 1965 both under 111.48 m^2 and to homes from 1940 to 1965 over 185.8 m^2.

IV. Discusssion

The statistical data collected from this study clearly indicated that homes built from 1965 to 1985 with over 185.8 m^2 were healthier with the results of the four-sense evaluation indicating the significance of = 0.05. The least healthy homes were those aged from 1903 to 1940, and 1940 to 1965 and smaller than 111.48 m^2.

Table 1. Values and ranks of measured variables for houses of less than 111.48 m^2.

Variables Measured/Year		**1901-1930**		**1940-1965**		**1965-1985**		**1989-2005**	
Measured Sense		**Data**	**Rank**	**Data**	**Rank**	**Data**	**Rank**	**Data**	**Rank**
Sound	**Db Inside Residence**	39.4	8	37	7	33	4	34.6	5
	Db Outside Residence	44.4	8	39	5	38	4	35.9	3
Touch	**Total Touch**	86.7	8	85	5	85	6	82	1.5
Sight	**Average Foot-candles**	92	3	96	8	93	4	51.2	1
	Average Percentage Of Natural Landscape Viewed From Window	59.6	8	98	5.5	97	4	97.2	3
	View of Appliances	98.7	8	97.67	5.5	97	4	97.2	3
Smell - Eaq	**Tsi Dust Track Average Inside**	0.06	7	0	4	0	8	0.04	5
	Difference Between Outside/Inside	0.11	7	0.1	1	0	8	0.1	6
	Ppbrae- Average Inside	61.1	3	35	2	211	5	285	6
	Difference Between Outside/Inside	649	6	665	7	490	4	431	3
	Q-Track-Humidity-Average Inside	10.4	7	15	8	4	1	6.29	3
	Q-Track-Humidity- Outside	84.7	5	94	7	93	8	84	4
	Q-Track-Temperature-Average Inside	11.3	6	12	7	9	4	18.1	8
	Q-Track-Temperature-Outside	86.3	3	91	7	93	8	74.3	1
Total	**Ranked Totals**	87	8	77.5	7	69	5	54.5	3.5
	Squared Totals	7569		6006		4761		2970	

Table2. Values and ranks of measured variables for houses greater than 185.8 m^2.

Variables Measured/Year		**1901-1930**		**1940-1965**		**1965-1985**		**1989-2005**	
Measured Sense		**Data**	**Rank**	**Data**	**Rank**	**Data**	**Rank**	**Data**	**Rank**
Sound	**Db Inside Residence**	32.3	2	35.8	6	31.44	1	32.54	3
	Db Outside Residence	35.88	2	40.7	7	31.57	1	39.44	6
Touch	**Total Touch**	84	4	85.67	7	82.34	3	82	1.5
Sight	**Average Footcandles**	95.6	6	96.09	7	66.08	2	93.58	5
	Average Percentage Of Natural Landscape Viewed From Window	53.34	6	57.5	7	38.34	2	43.75	3
	View of Appliances	98	7	97.67	5.5	96.67	2	96.34	1
Smell – Eaq	**Tsi Dust Track Average Inside**	0.039	2	0.039	2	0.039	2	0.0494	6
	Difference Between Outside/Inside	0.089	3.5	0.089	3.5	0.085	2	0.0914	5
	Ppbrae- Average Inside	25.58	1	82.84	4	659.7	8	544.92	7
	Difference Between Outside/Inside	681.1	8	617.2	5	52.67	1	174.42	2
	Q-Track-Humidity-Average Inside	9.07	4	9.62	6	5.11	2	9.19	5
	Q-Track-Humidity- Outside	78.57	2	78.7	3	77.4	1	84.9	6
	Q-Track-Temperature-Average Inside	5.61	2	10.1	5	6.58	3	3.94	1
	Q-Track-Temperature-Outside	87.43	5	90.94	6	87.37	4	82.77	2
Total	**Ranked Totals**	54.5	3.5	74	6	34	1	53.5	2
	Squared Totals	2970		5476		1156		2862	

Table 3. Absolute differences between the ranked treatments.

Rank	***Rank 1 minus other ranks***	*Rank 2*	*Rank 3*	*Rank 5*	*Rank 6*	***Rank 7***
2	-19.5					
3.5	-20.5	-1				
3.5	-20.5	-1				
5	-35	-15.5	-14.5			
6	-40	-20.5	-19.5	-5		
7	-43.5	-24	-23	-8.5	-3.5	
8	-53	-33.5	-32.5	-18	-13	-9.5

This information recognizes a healthier time period in the USA when there was much prosperity. More city dwellers were moving to the suburbs for more open space landscapes. Design elements and grandiose construction was more of a consideration on larger plots of land especially with the architectural ideas from Frank Lloyd Wright evolving new ideas with natural materials. More impressive architects emerged with Post-Modernism added detail to construction specifying variety for the public eye. More wood interest influenced homes to have more vernacular, custom details, as evident in the interior designs of Frank Lloyd Wright and the Arts and Crafts movement. Continued interest with wood concepts proliferated custom furniture as their colors, shapes, and texture interacted with the architecture. The emphasis of the outside environment blending with the inside environment is evident with designs from Frank Lloyd Wright. As these great design concepts proliferated, distinguished individuals desired to have more.

Stronger building construction, attention to detail, and better insulation could be seen with the study results indicating the first group to have the lowest decibels measured. The second ranked homes were aged 1901 to 1930 and over 185.8 m^2. The third were the newest homes ages 1989 to 2005 regardless of the size. Another consideration as to why this age home and size was considered the best for sound could also be with the use of large plot sizes that would put the home further away from their neighbors as well as the street.

Data collected for touch indicated the best results to be the newest aged homes, 1989 to 2005, regardless of size. The homes aged 1965-1985 over 185.8 m^2 ranked third. One consideration for newer homes to be better in this area could be from the heightened consideration of style and finish selections in newer homes. There are many shows on TV displaying new ideas for flooring, wall colors, tiles, window treatments and other elements to make a home visually more appealing.

This study's data indicated evidence that even in the home with the best natural light, there was only enough illumination for ambient lighting. The best average was measured between 35-50 foot-candles in the homes between the ages of 1965 to 1985. The third ranked were residents aged 1985 to 2005 and over 185.8 m^2.

There seemed to be more windows in homes aged 1965 to 1985 when the study was conducted. The larger plot sizes could also allow for more natural light to filtrate into the home.

Results from smell, indoor air quality, ranked better in homes over the age of 1965 and over 185.8 m^2. The equipment used during this study measured the amount of particulate matter, called a Dust Track. This specified results with the greatest difference between inside and outside was from the homes aged 1965 to 1985 over 185.8 m^2. The best data for the least amount of particles present inside indicated a tie for all home sizes over 185.8 m^2, except the most recent age, 1998 to 2005. The first rank was for homes smaller, 1940 to 1965, which could be due to the lack of occupants in the homes. Mostly, all the dust particles inside the homes were within .01 mg/m3, except the smaller older homes. MIOSHA prefers the limit to non-toxic dust over an eight hour average to be 5mg/m3.

The best data for the least amount of particles present inside was for the older homes. Normal levels are between 200-500 ppb. Newer homes were higher; aged 1965 to 1985 over 2000ft2 was 660 ppb, and 1998 to 2005 over 185.8 m^2 was 545 ppb.

Measurement of relative humidity (RH) results indicated the best homes aged 1965 to 1985 over 185.8 m^2. The inside humidity measured 45.11 % RH with a difference from outside of 68 % RH. On the average the smaller homes had consistently higher rates.

Speculation might lead to the belief that larger constructed homes could have had the best quality products, as well as better HVAC systems supporting improved circulation. This would have reduced the interior air pollutants, as well as dust and moisture concentrations, thus adding to a healthier interior air quality environment.

Figure 5. A view of historic Paris, taken from the Montparnasse Tower overlooking the Luxembourg Palace and Notre Dame to the north-east. (copyright © 2005 Jon Bryan Burley all rights reserved, used by permission)

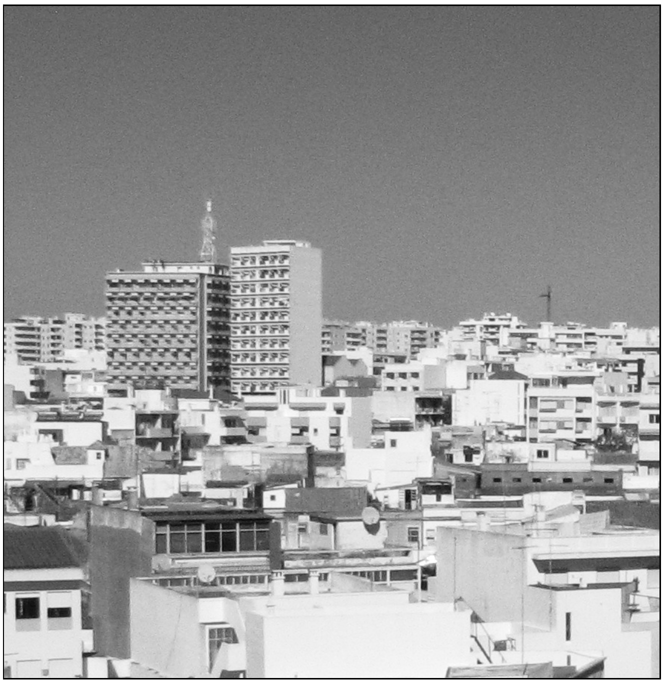

Figure 6. A view of the high-density residential setting in Faro, Portugal, looking north from the city center. (copyright © 2010 Jon Bryan Burley all rights reserved, used by permission)

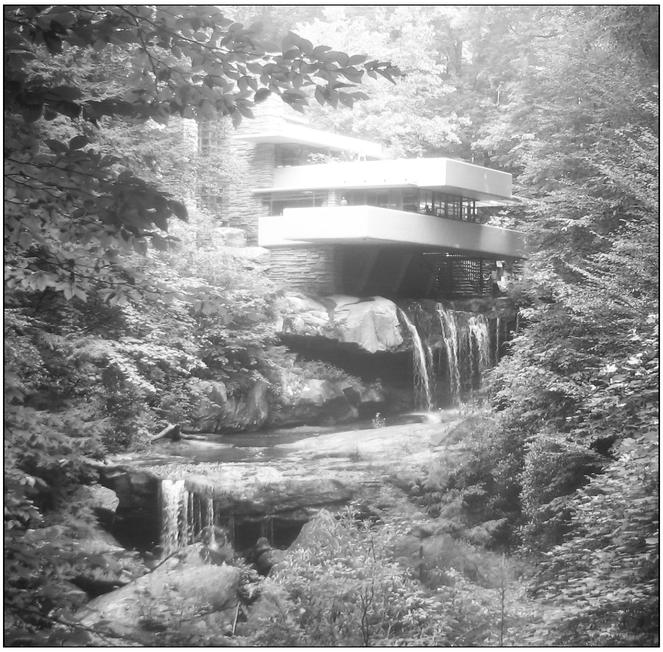

Figure 7. A view of the Kaufmann Residence (Fallingwater House), in Pennsylvania, USA. (copyright © 2007 Jon Bryan Burley all rights reserved, used by permission)

While this study has produced statistically significant results, the results are not definitive and cannot be applied to residential settings in other regions of the world. Instead, this study provides a framework upon which similar types of studies could be conducted in other regions of the planet. For example, in historic Paris, France, where there are few single-family home dwellings and the buildings were constructed in a earlier time-frame, the results of our study would not be very applicable (Figure 5). Yet, we would encourage investigators to conduct similar studies to assess these Parisian residential environments. In addition, many areas in the world have high density, newly built homes such as the ones illustrated in Faro, Portugal (Figure 6). These high-density homes merit investigation also, especially when many places the world are considering constructing many more of these densely packed living quarters. Finally, there are many uniquely built homes such as the Kaufmann Residence designed by Frank Lloyd Wright (Figure 7). These “one-of-a-kind” homes have special spatial properties (spectacular views, spacious living, special materials) that merit investigation and may provide insight into the breadth of design possibilities in a residential setting.

V. Conclusion

The interaction between the building construction, interior architecture, and occupant’s health are evident as being closely related. Clearly, conclusive evidence suggests not only the need for more sustainable construction materials, but professionals to contemplate sustainable construction applications and products, drawing on their knowledge and development of design practice. There are six areas of focus for sustainable influence that have been recognized by USGBC LEED rating systems. Increased education can promote a better understanding of the long-term savings, as well as encourage smoother transition for continued energy conservation. This study further verifies the necessity for healthier residential environments as a complement to sustainable construction.

Environments that positively influence emotions can also have a healthier impact. Research about the influence of natural light on individual health was just beginning to be researched as Ulrich discovered with the positive influence windows had on the health of hospital patients, and Rosenthal realized the effects of full-spectrum light on SAD patients [4]. Holistically, psychological perceptions can alter physiological changes [2]. For example, an individual in a high stress occupation is more prone to hypertension and heart attacks. Altering design to promote positively engaging interior environments can improve psychological and physical health. As every individual interacts with their environments through their senses, environments that influence individual senses in a positive way can promote health and well-being.

With the holistic perspective of emotional, spiritual, and social affiliation to the physical environment need to be included for consideration with individual environments. Design for holistic environments can start with the exterior location considering landscape and social interaction to accommodate enjoyment with both. Recognizing the need of the occupant with social, spiritual, and physical needs encourages the function and shape of the interior environments. As individual occupant needs and wants are examined, environments can be designed promoting health as viewed with their senses. Recognizing and promoting Maslow's hierarchy of needs can also influence the holistic design for interior shape, color, materials, function and occupant interaction.

A truly environmentally healthy design can be instituted where the designer creates an environment that promotes health for the occupant, depending upon their physical, psychological or social needs. With consideration to this thesis, and the five senses mentioned, design and construction could be formulated with evidence-based data to recognize healthy attributes for the encouragement and maintenance of healthy interior environments. For example, a design for an individual's home with SAD disease could specify a lot of tall windows, using mostly southern exposure, three sky-lights facing the south, and light bulbs that were at least 5500°K. These effects would increase the full spectrum amount of light in a room and decrease SAD symptoms during the fall/winter months when there is less natural light. This would encourage physical health, which could then enhance emotional calmness, which might then increase social interaction, which could then allow the occupant to feel content with a sense of belonging. This could then foster happiness with increased well-being.

Future research can be done to indicate improvement with accuracy and knowledge for the design and construction of health related principles for interior environments. One consideration not involved with this study would be electronic influence on individual health. There seems to be more interaction with electronic devices all the time. Though sustainable finishes tend to be smoother and non-porous, they tend to reflect more sound. What flooring product(s) and other finishes be indicated to be sustainable, bacterial resistant and absorb sound all at the same time.

Another study can be toward the concept of multi-functional space. What finishes, colors, and furniture would be involved and how would that be determined. Along with the concept of space usage, could also be age factor. The difference between the use of a space with age can be the colors, finishes and furniture that goes within the space. Most individuals relate well to what they are familiar with, so the older individual would easier relate to "dated" furniture as well as color and finishes.

Not enough attention has been toward emotional awareness of interior finishes and spaces. Consideration of factors that could come into play are sound, light, color, texture with furniture/ finishes, and size of space. Pieces of nature are comfortable and familiar to most individuals, so what natural elements could be considered that would emotionally influence an interior environment.

This study considered the interior residential environments with evaluation tools relating to four senses. There could be research about the consideration of healthy interior environments for individuals lacking one of their senses. Some environmental studies could be about the best communication tools for an individual to feel comfortable within this environment, and how could that determine safety?

With the realization that the average American spends over 90 percent of their time indoors [1], research toward healthier interior environments can only continue to grow with new ideas for construction and design.

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