Spring 2015

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Inquiry Editors

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FOREWORD

I am pleased to present to you Volume 18 of the Inquiry Undergraduate Research Journal. The Inquiry Journal was developed by the Teaching Academy of the University of Arkansas and is supported financially and conceptually by the offices of the Provost and the Vice Provost for Research and Economic Development. Inquiry provides a forum for sharing the research and creative endeavors of undergraduate students and their faculty mentors at the University of Arkansas.

Volume 18 of the Inquiry Undergraduate Research Journal features the unique contributions of undergraduate student authors and their faculty mentors. The research and creative endeavors that are published in the Inquiry Undergraduate Research Journal span diverse fields at the University of Arkansas, including Biological & Chemical Engineering; Landscape Architecture; Psychological Science; Music, Latin American & Latino Studies, Economics, and World Languages. Casey Gibson, Karla G. Morrissey and their faculty mentor, Dr. Roy McCann, examined the behavior of vanadium redox flow batteries as a suitable option for storing intermittent sources of alternative energies. Using gender schema theory, Eric Carter and his faculty mentor, Dr. Ana J. Bridges, examined the ways in which intercourse position preference among men who have sex with men is associated with gender roles, internalized homophobia, and mental health. Hannah L. Hefner and her faculty mentor, Professor Phoebe M. Lickwar, to develop an innovative approach for transforming unmaintained land within cities.

I would like to extend a special thank you to the many faculty members who volunteer their time and expertise in order to provide comprehensive reviews of student manuscripts. While we are unable to publish all of the submitted manuscripts, we also want to thank the students and faculty mentors for their diligent efforts. Additionally, I would like to thank Beth Juhl and Arthur Morgan, Mullins Library, for their efforts in publishing each volume electronically. Please see the next page for a list of faculty and staff who play an integral role in publishing each volume of the Inquiry Undergraduate Research Journal.

We plan to publish Volume 19 of the Inquiry journal in September 2015. I encourage undergraduate students and faculty mentors to consider submitting their manuscript to the Inquiry Undergraduate Research Journal by May 16th for consideration.

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Who’s On Top? The Mental Health of Men Who Have Sex with Men

By: Eric R. A. Carter
Department of Psychological Science

Faculty Mentor: Dr. Ana J. Bridges
Department of Psychological Science

Abstract

Despite most men who have sex with men (MSM) expressing intercourse position preference (e.g., “top”, “versatile”, or “bottom”), there is little information regarding sexual behavior and mental health sequelae. From the perspective of gender schema theory, the current study examined how position preference related to gender roles, internalized homophobia, and mental health. A total of 70 MSM (U.S. residents, $M$ age = 28.89 years, 68.6% White) were recruited for an online study and grouped according to position preference. Groups were mostly similar across demographic variables, although bottoms had fewer sexual partners and lower condom use than tops and versatiles. In terms of gender roles, tops and versatiles were significantly higher in both masculine and feminine traits than bottoms. Tops were significantly more likely to report internalized homophobia than versatiles and bottoms. After controlling for masculinity, versatiles had the highest mental health. Results suggest further study of different sub-populations of MSM is warranted.

Keywords: anal sex, gender roles, homophobia, mental health

As tolerance toward homosexuality has increased in the U.S., so too has research regarding the health and mental health of homosexual populations. One of the most researched areas regarding the health of homosexual populations, particularly in men who have sex with men (MSM), is sexual disease risk. There is a wealth of research on the habits, behaviors, and mental health of MSM afflicted with human immunodeficiency virus (HIV) or acquired immune deficiency syndrome (AIDS) (Baggaley, White, & Boily, 2010; Koblin et al., 2006; Mustanski, Newcomb, Du Bois, Garcia, & Grov, 2011; Safren, Reisner, Herrick, Mimiaga, & Stall, 2010). Much of the research has focused on the sexual behaviors (e.g., penetrative anal sex without the use of a condom) that increase the risk of transmission of sexually transmitted infections (STI), especially HIV (Jin et al., 2009; Koblin et al., 2006; Thomas et al., 2009; Van Druten, Van Griensven, & Hendriks, 1992).

Two behaviors that have been examined in relation to HIV and sexually transmitted infection (STI) risk consist of engaging in either receptive or in insertive anal intercourse (Jin et al., 2009; Thomas et al., 2009; Van Druten et al., 1992). Those who engage primarily in insertive anal intercourse are referred to as adopting an active, top, or insertive role; those who engage in receptive anal intercourse are often referred to as adopting a passive, bottom, or receptive role. Some men engage in just one anal sex role (receptive or insertive), while others are more versatile in their behavior (Patterson & D’Augelli, 2013). Nearly 90% of MSM identify with a self-label of “top,” “bottom,” or “versatile” (Hart et al., 2003; Wei & Raymond, 2011). Prevalence rates are approximately 35% top, 25% bottom, and 40% versatile (Grov, Parsons, & Bimbi, 2010; Wei & Raymond, 2011). HIV and other STI risks are increased by adhering to a bottom anal sex role during intercourse (Wegesin & Meyer Bahlburg, 2000). A meta-analysis found that per-partner risk of HIV infection during unprotected sex was 40.4% for bottoms while risk was only 21.7% for tops (Baggaley et al., 2010).

In addition to sexual disease risk, some researchers have examined whether anal sexual preferences are associated with specific gender roles. For example, preferring a bottom role is often associated with being passive or feminine, while preferring a top
role is associated with being aggressive and masculine (Wei & Raymond, 2011). Weinrich, Grant, Jacobson, Robinson, and McCutchan (1992) found that preference for bottom roles in 102 MSM residing in a large west coast city was associated with childhood feminine gender expression. Kippax and Smith (2001) examined power relationships and conceptualization of MSM’s intercourse position preference and relationships, finding bottom preference is associated with being passive, weak, and feminine, while top preference is associated with being active, strong, and masculine.

In many relationships among MSM, masculinity is often viewed as ideal, whereas femininity is considered undesirable (Lanzieri & Hildebrandt, 2011; Patterson & D’Augelli, 2013). This mirrors the general societal preference for masculinity over femininity in Western cultures (Connell, 2005). For example, Bailey, Kim, Hills, and Linsenmeier (1997) investigated MSM’s romantic partner preferences by examining characteristics of ideal partners that men listed on a prominent dating website. In this investigation, masculinity was the most commonly listed desirable trait in a potential partner. Furthermore, no single profile listed masculinity as an undesirable trait. Feminine traits, however, were commonly listed as undesirable. Because masculinity is a valued trait in men and femininity often is not, and because bottom preference is associated with femininity, it is possible that men who prefer bottom roles and who are considered not very masculine may be at risk for depression or other mental health problems. Indeed, Rieger and Savin-Williams (2012) found that gender nonconformity, above and beyond sexual orientation, was associated with experiences of discrimination in gay, lesbian, and bisexual participants. In addition, Sandfort, Melendez, and Diaz (2007) found experiences of discrimination mediated the association between gender nonconformity and poor mental health in a large sample of Latino gay and bisexual men.

In addition to the potentially negative mental health effects of gender nonconformity (in the form of high femininity and low masculinity), some MSM may also have high levels of internalized homophobia (Williamson, 2000). Studies have found that gay men with higher rates of internalized homophobia report lower relationship satisfaction and duration, decreased openness about sexual orientation (Ross & Rosser, 1996), increased psychological problems such as substance abuse, increased self-injurious behaviors (Williamson, 2000), and higher depression (Herek, Cogan, Gillis, & Glunt, 1998) than gay men with little or no internalized homophobia.

In sum, the research to date demonstrates a bottom anal sex role preference in MSM is associated with increased sexual health risk and increased gender traits are considered androgynous. Finally, men and women who are low on both feminine and masculine traits are considered undifferentiated.

Many studies have pointed to the benefits of a masculine gender role orientation and the relatively detrimental effects of a feminine orientation for the mental health of both men and women (e.g., Bassoff & Glass, 1982; Cella, Iannaccone, & Cotrufio, 2013; Taylor & Hall, 1982). Alternatively, there is a sizeable literature suggesting people who are more androgynous in their gender roles, endorsing both masculine and feminine traits, have the best mental health of all (e.g., Cheng, 2005; Coleman, Kaplan, & Casey, 2011; Lefkowitz & Zeldow, 2006; Prakash et al., 2010; Woodhill & Samuels, 2003). In part this may be because such individuals have greater psychological flexibility and are able to be either more assertive or more cooperative, depending on the demands of specific situations. It may also be that in patriarchal societies that value masculinity over femininity, people (but especially men) who fail to embody valued masculine traits are subject to more discrimination than people who display high masculinity. Indeed, Gordon and Meyer (2007) found that gender nonconformity, above and beyond sexual orientation, was associated with experiences of discrimination in gay, lesbian, and bisexual participants. In addition, Sandfort, Melendez, and Diaz (2007) found experiences of discrimination mediated the association between gender nonconformity and poor mental health in a large sample of Latino gay and bisexual men.

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In sum, the research to date demonstrates a bottom anal sex role preference in MSM is associated with increased sexual health risk and increased gender
nonconformity compared to top sex role preference. Also, studies find both gender nonconformity and internalized homophobia are negatively associated with mental health in MSM. However, much of the research with MSM has focused on HIV risk or HIV-positive samples, limiting generalizability. In addition, studies have not focused much attention on top or versatile intercourse position preferences in MSM as they relate to mental health, perhaps because so much of the work has been focused on sexual health risk and the risk of HIV transmission is lower in this group. Finally, the constructs of anal sex role preference, gender role orientation, internalized homophobia, and their mental health sequelae have not been investigated together in a single sample of men.

**Purpose**

The first exploratory aim of this research was to determine demographic characteristics associated with anal intercourse position preference. The second aim was to examine how position preference related to internalized homophobia and gender roles, and how these in turn related to mental health. Consistent with gender role schema theory, we anticipated that gender congruence (i.e., masculinity) would be highest in men who identified as “top” or “versatile” (Hypothesis 1), while non-congruence (i.e., femininity) would be higher in men who identified as “bottom” (Hypothesis 2). We further anticipated both versatile and bottom position preferences would be associated with lower internalized homophobia, compared to a top preference (Hypothesis 3). Finally, we expected a gender non-congruent orientation (i.e., higher femininity; Hypothesis 4) and higher internalized homophobia (Hypothesis 5) would be associated with lower global mental health, while gender typical (sex-typed) and androgynous gender roles would be associated with greater global mental health.

**Method**

**Participants**

A total of 105 individuals were recruited for participation in this study. Of these, 27 were excluded due to lack of completion or for not meeting requisite demographic criteria (i.e., having had a sexual experience with another man, male gender, age > 17 years, and resident of the United States). Of the 78 who completed the survey, eight participants consistently selected “I do not use labels” on questions assessing anal intercourse position preference. Given this was the primary grouping variable used in the study, these participants were also excluded from analyses. Thus, the final sample size used in the statistical analyses and comparisons consisted of 70 men.

The average age of the final sample was 29.89 years ($SD = 8.43$, range 20-55). In terms of race, 68.6% of the sample self-reported being White. A total of 47.1% of the sample reported adhering to a religion. The average educational level was 4.69 ($SD = 1.56$), ranging between 4 (*some college*) and 5 (*undergraduate degree*). Fifty-seven percent of participants were employed full-time, with an average annual income between $25,000 and $49,999. About 57% of participants reported being in a relationship, with an average duration of 3.32 years ($SD = 4.63$, range one month – 20 years).

**Procedures**

A majority (86%) of participants were recruited via MechanicalTurk, an internet-based recruitment and participant payment service. The recruitment message informed participants that they were going to complete a survey concerning the sexual behavior of MSM. As per MechanicalTurk’s policy, the recruitment message specified that the content of the survey was appropriate for adults only and filters were put in place that required participants to have already verified their age and willingness to see survey requests such as this; individuals younger than 18 were not able to see the recruitment message. Participants were also informed they would receive a modest monetary compensation for completing the survey.

In addition to being MSM, aged 18 and over, and living in the United States, participants also had to meet MechanicalTurk criteria as “Master Workers”. This elite status indicated that the participants in the study had a high degree of accuracy and completion of work and a high approval rate from recruiters on other MechanicalTurk tasks. After meeting all of the criteria, the recruited participants were provided with a short memorandum about the study and a link to the SurveyMonkey questionnaire itself. At the end of the study, participants were given a code that enabled them to receive payment via MechanicalTurk. In order to enhance recruitment, we increased the amount of compensation from the initial $1 to $2, $3, and finally $4. Thirty-two participants received $4, 5 received $3, 3 received $2, and 27 received $1.

Fourteen percent of participants were recruited via snowball sampling. In particular, the researcher and his advisor contacted acquaintances who met...
criteria and asked if they would participate and recruit others who met criteria to also take the survey. Because they were not affiliated with Mechanical Turk, none of the participants recruited in this method were compensated.

Once all participants accessed the questionnaire, they were first provided with information about the study and indicated their consent by clicking on a button. Next, participants were presented with a series of questions (provided below). Once participants completed the questions, a debriefing page was presented. Participants were given additional information regarding the purpose of the study and they were thanked for their participation. All study procedures were approved by the University of Arkansas Institutional Review Board.

**Measures**

**Demographic characteristics.** Demographic questions were asked concerning age, ethnicity, religion, religiosity, educational attainment, employment status, annual income, relationship status, sexual orientation, sexual satisfaction, degree of openness regarding sexual orientation, condom use, and pornography use. Age was a free response and was coded continuously. Ethnicity was a multi-select item that was recoded into a dichotomous White/non-White item. Multiple options (single select) were offered for religious denomination; however this variable was recoded into a dichotomous atheist/ theist item. Religiosity was coded from 1 (not at all religious) to 5 (extremely religious). Educational attainment was coded 1 (no high school), 2 (some high school), 3 (high school diploma), 4 (some college), 5 (undergraduate degree), 6 (some higher/graduate education), 7 (masters level degree), and 8 (doctoral level degree). Employment status responses were recoded into a dichotomous item: employed full-time/not employed full-time. Annual income was coded in $25,000 increments from 1 (less than $25,000 per year) to 7 (greater than $150,000 per year). Relationship status was recoded into a dichotomous variable: single/partnered. Sexual orientation was measured by self-reported interest in one or both sexes 1 (sexual interest in women only) to 5 (sexual interest in men only). Sexual satisfaction was coded from 1 (very dissatisfied) to 5 (very satisfied). Openness with others regarding sexual orientation was recoded into a dichotomous item: closeted/out. Condom use was coded from 1 (never, 0% of the time) to 5 (always, 100% of the time). Pornography use was coded from 1 (never) to 7 (multiple times per day).

**Anal intercourse position preference.** Since all previous studies used a single question to establish anal intercourse position preference (IPP) and this study’s primary measure of interest was IPP, we created a six-item questionnaire that assessed IPP. Items on the questionnaire began by asking *In the past 12 months* and inquired about past anal sex behavior (*When I have had sex, I have usually been...*), fantasy (*I have primarily fantasized about being... and If I could have any sort of anal sex I wanted, I would want to...*), self-labelling (*I think of myself as a... and I use the self-label of...*), and others’ labelling of the participant (*People I know or have had sexual encounters with know me as a...*). The response options for the six questions were: (1) top (inserter, pitcher, penetrator), (2) versatile top (usually “top,” but occasionally bottom), (3) versatile (“vers,” flip flop, doing both in nearly equal amounts), (4) versatile bottom (usually “bottom,” but occasionally top), and (5) bottom (receiver, catcher, penetrated). These response choices included multiple terms of reference (slang, etc.) for the IPP labels so that a participant’s personal label of choice would likely be listed within one of the five choices. Participants were also given the options of indicating “these labels don’t apply to me,” and “other (please specify).”

Inter-item correlations between the six items ranged from *r* = .665 to .981, and all were significant at *p* < .001. Cronbach alpha for the six-item scale was .96. Given the high internal consistency, an average IPP score was calculated for each participant. Scores ranged from 1 (top) to 5 (bottom). The mean score was then recoded into three groups. Scores ranging from 1 to 1.99 were recoded as top, scores from 2.00 to 3.99 became versatile, and scores of 4.00 to 5 became bottom.

**Gender roles.** The Bem Sex Role Inventory (Bem, 1974; Hoffman & Borders, 2001) was administered to assess participants’ gender roles. The Bem contains 60 adjectives (1/3 of which are typically associated with masculinity, 1/3 of which are typically associated with femininity, and 1/3 of which are typically not associated with one gender or the other). Sample traits on the masculinity subscale include self-reliant and aggressive, while sample traits on the femininity subscale include sensitive and compassionate. Two subscale scores, femininity and
masculinity, were calculated by averaging the 20 items assessing femininity and masculinity, respectively. Higher scores indicated greater endorsement of those gendered traits. Studies have shown the Bem’s internal reliability is good, with Cronbach alpha values typically between .75 and .90 (reviewed in Hoffman & Borders, 2001). Recent evidence of content validity was demonstrated in a study, with men being significantly more likely to be categorized as having a male sex-typed gender role and women being significantly more likely to be categorized as having a female sex-typed gender role (Marrs, Sigler, & Bramer, 2012). In the current study, internal consistency values were .93 for the masculinity subscale and .89 for the femininity subscale.

**Internalized homophobia.** The Reactions to Homosexuality Scale, revised (Smolenski, Diamond, Ross, & Rosser, 2010) was used to assess internalized homophobia. This is a seven-item questionnaire assessing three domains of homophobia: personal comfort with a gay identity (3 items), social comfort with gay men (2 items), and public identification as gay (2 items). Sample items include, *Even if I could change my sexual orientation, I wouldn’t and I feel comfortable being seen in public with an obviously gay person.* Items are answered on a 7-point Likert scale from 1 (strongly disagree) to 7 (strongly agree). The original scale measures positive reactions to homosexuality, so scores were reverse-coded such that higher scores indicated higher internalized homophobia.

The authors demonstrated adequate internal consistency (Cronbach alpha coefficients ranging from .60 to .76 for the individual subscales) and high subscale correlations (ranging from .40 to .55). Criterion validity was demonstrated by the authors: men who were involved in gay organizations, were not in relationships with other men, and did not discuss their sexual orientation with their primary care physicians scored higher on the subscales of internalized homophobia than men integrated in the gay community, in gay relationships, and who openly discussed their sexual orientation with their physicians (Smolenski et al., 2010). In the current study, internal consistency for the 7-item scale was .77.

**Mental health.** The Brief Symptom Inventory (BSI) was administered to evaluate psychiatric distress and mental well-being (Derogatis & Melisaratos, 1986). The BSI is a 53-item measure assessing psychiatric symptoms across nine dimensions: somatization, obsessive-compulsive, interpersonal sensitivity, depression, anxiety, hostility, phobic anxiety, paranoid ideation, and psychoticism. Items ask about how often the respondent has been distressed or bothered by the symptoms over the past week and are

### Table 1. Demographic characteristics of the sample by intercourse position preference group.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Top (n = 30)</th>
<th>Versatile (n = 28)</th>
<th>Bottom (n = 12)</th>
<th>F or $X^2$ statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>31.70 (7.56)</td>
<td>28.07 (8.48)</td>
<td>29.58 (10.08)</td>
<td>$F (2, 67) = 1.36, p = .263$</td>
</tr>
<tr>
<td>White race</td>
<td>18 (62%)</td>
<td>22 (79%)</td>
<td>5 (42%)</td>
<td>$X^2 (2) = 5.26, p = .072$</td>
</tr>
<tr>
<td>Atheist</td>
<td>13 (43%)</td>
<td>14 (50%)</td>
<td>10 (83%)</td>
<td>$X^2 (2) = 5.66, p = .059$</td>
</tr>
<tr>
<td>Religiosity†</td>
<td>2.10 (1.27)</td>
<td>1.79 (0.92)</td>
<td>1.67 (1.23)</td>
<td>$F (2, 67) = 0.86, p = .426$</td>
</tr>
<tr>
<td>Educational attainment‡</td>
<td>4.77 (1.63)</td>
<td>4.57 (1.57)</td>
<td>4.75 (1.42)</td>
<td>$F (2, 67) = 0.12, p = .884$</td>
</tr>
<tr>
<td>Employed full time</td>
<td>19 (65%)</td>
<td>11 (41%)</td>
<td>10 (83%)</td>
<td>$X^2 (2) = 7.16, p = .028$</td>
</tr>
<tr>
<td>Annual income†</td>
<td>2.37 (1.45)</td>
<td>2.46 (1.69)</td>
<td>2.25 (1.14)</td>
<td>$F (2, 67) = 0.09, p = .915$</td>
</tr>
<tr>
<td>Sexual orientation‡</td>
<td>2.77 (1.22)</td>
<td>3.50 (1.43)</td>
<td>4.75 (0.45)</td>
<td>$F (2, 67) = 11.38$</td>
</tr>
<tr>
<td>Single (not in a relationship)</td>
<td>11 (37%)</td>
<td>17 (61%)</td>
<td>2 (17%)</td>
<td>$X^2 (2) = 7.48, p = .024$</td>
</tr>
<tr>
<td>Number of sexual partners (past year)§</td>
<td>3.10 (1.16)</td>
<td>3.14 (1.27)</td>
<td>2.08 (0.67)</td>
<td>$F (2, 67) = 5.36, p = .020$</td>
</tr>
<tr>
<td>Sexual satisfaction§</td>
<td>3.77 (1.25)</td>
<td>3.89 (0.97)</td>
<td>4.17 (1.34)</td>
<td>$F (2, 66) = 0.51, p = .606$</td>
</tr>
<tr>
<td>Condom use§</td>
<td>3.60 (1.43)</td>
<td>3.69 (1.44)</td>
<td>2.08 (1.51)</td>
<td>$F (2, 65) = 5.79, p = .005$</td>
</tr>
<tr>
<td>Pornography use§</td>
<td>5.03 (1.16)</td>
<td>4.57 (1.10)</td>
<td>4.83 (1.70)</td>
<td>$F (2, 67) = 1.00, p = .373$</td>
</tr>
</tbody>
</table>

**Note.** Means sharing a letter in their superscript are not significantly different at the .05 level on Fisher LSD post-hoc tests.
scored on a 5-point Likert scale, from 0 (not at all) to 4 (extremely). Sample items include feeling no interest in things and spells of terror or panic. The mean of all items was calculated to achieve a global psychiatric distress score. Higher numbers equal higher psychiatric distress (worse mental health, more problems). Internal consistency values for the symptom subscales range from .71 to .85, with global distress total scores showing excellent test-retest reliability over a two-week span ($r_{xx} = .90$). Convergent validity has been demonstrated by positive correlations between BSI subscales and theoretically similar subscales of the Minnesota Multiphasic Personality Inventory. In the current study, internal reliability for the global distress score was .97.

Data from the SurveyMonkey questionnaire were transferred into IBM SPSS Statistics program wherein analyses of variance (ANOVA), chi square tests for independence, and analyses of covariance (ANCOVA) were conducted. Post-hoc tests were run using the Fisher LSD test. For all tests, alpha levels for evaluating statistical significance were set at 0.05.

**Results**

**Part 1: Demographic Correlates**

A series of one-way between-groups analyses of variance (ANOVAs) and chi square tests were conducted to explore the relation of intercourse position preference (IPP) to numerous demographic variables, including age, educational attainment, annual income, religiosity, sexual orientation, sexual satisfaction, frequency of condom use, number of sexual partners in the past year, and pornography use. Means and standard deviations are reported in Table 1. The three IPP groups (tops, versatiles, and bottoms) did not differ significantly in average age, race/ethnicity, religious affiliation, religiosity, educational attainment, annual income, sexual satisfaction, or pornography use. Significant differences did emerge for full-time employment status, with bottoms (83%) significantly more likely to report full-time employment than tops (65%) or versatiles (41%) ($p = .028$).

Regarding relationship and sex questions, other differences between the groups emerged. Versatiles (61%) were significantly more likely to be single compared to tops (37%) and bottoms (17%) ($p = .024$). Differences also emerged in self-reported sexual orientation. In particular, utilizing a one-way between-groups ANOVA, we explored the relation between IPP and self-reported sexual orientation. Significant differences were found between all groups [$F (2, 67) = 11.38, p < .001$]. Post-hoc comparisons using the Fisher LSD test indicated significant differences between all three position preference groups (all $p$ values < .03). In particular, bottoms reported the highest levels of homosexuality ($M = 4.75, SD = 0.45$). Versatiles ($M = 3.50, SD = 1.43$) reported less interest in men than bottoms, but more than tops, who reported the highest levels of sexual interest in women ($M = 2.77, SD = 1.22$).

A one-way between-groups ANOVA compared IPP groups on the number of sexual partners in the past year. There was a statistically significant difference among the groups [$F (2, 67) = 4.13, p = .020$]. Post-hoc comparisons using the Fisher LSD test indicated that the mean score for bottoms ($M = 2.08, SD = 0.67, ~one sexual partner in the past year) was significantly different from tops ($M = 3.10, SD = 1.16, ~two sexual partners in the past year) and from versatiles ($M = 3.14, SD = 1.27, ~two sexual partners) ($p = .011$). Tops and versatiles did not significantly differ from each other.

There was also a statistically significant difference in condom use between groups [$F (2, 65) = 5.79, p = .005$]. Bottoms ($M = 2.08, SD = 1.51$) used condoms significantly less often than both tops and versatiles. Tops ($M = 3.60, SD = 1.43$) and versatiles ($M = 3.69, SD = 1.44$) did not significantly differ from each other in terms of condom use.

**Part 2: Hypothesis Tests**

**H1: Intercourse position preference (IPP) and masculinity.** A one-way between-groups ANOVA was conducted to compare the three IPP groups on masculinity scores, as measured by the relevant subscale of the Bem. Table 2 provides a summary of the results. There was a statistically significant difference in Bem masculinity scores for the three groups [$F (2, 67) = 8.57, p < .001$]. Post-hoc comparisons using the Fisher LSD test indicated that bottoms ($M = 3.48, SD = 1.38$) had significantly lower masculinity scores than did tops ($M = 4.78, SD = 0.98$) and versatiles ($M = 4.63, SD = 0.66$) while tops and versatiles did not differ from each other. Hypothesis 1 was therefore supported.

**H2: IPP and femininity.** Another one-way between-groups ANOVA was conducted to explore the relation of IPP and femininity as measured by the relevant subscale of the Bem (Table 2). There was a statistically significant difference in scores between the three groups [$F (2, 67) = 6.75, p = .002$]. Post-hoc
comparisons using the Fisher LSD test indicated that the mean femininity scores for bottoms ($M = 3.53, SD = 1.30$) was significantly lower than that of tops ($M = 4.26, SD = 0.91$) and versatiles ($M = 4.67, SD = 3.53$) which did not differ significantly from each other. Hypothesis 2 was therefore not supported.

**H3: IPP and internalized homophobia.** A one-way between-groups ANOVA was conducted to explore the relation between intercourse position preference (IPP) and internalized homophobia (Table 2). There was a statistically significant difference in mean scores for the three groups [$F(2, 67) = 3.54, p = .034$]. Post-hoc comparisons using the Fisher LSD test indicated that tops ($M = 3.17, SD = 1.46$) had significantly higher internalized homophobia scores than did versatiles ($M = 2.46, SD = 0.91$) and bottoms ($M = 2.37, SD = 0.62$). Bottoms and versatiles did not differ significantly from each other. Hypothesis 3 was therefore supported.

**H4: Femininity and global mental health.** To address the fourth hypothesis, Pearson product-moment correlations were computed between Bem femininity scores and BSI global distress scores. Results are summarized in Table 3. The correlation between Bem femininity scores and BSI was $r = -.106, p = .383$. Therefore, Hypothesis 4 was not supported. On the other hand, Bem masculinity scores and the BSI were significantly related, $r = -.431, p < .001$, indicating higher endorsement of masculine gender traits was associated with lower psychiatric distress.

**H5: Internalized homophobia and global mental health.** A Pearson product-moment correlation was computed between internalized homophobia, as measured by the Reactions to Homosexuality Scale, and psychiatric distress, as measured by the BSI global score (Table 3). The resulting correlation indicated the two were not significantly related, $r = -.067, p = .581$. Furthermore, a one-way between-groups ANOVA comparing the three IPP groups on mean BSI scores was not significant (Table 2). Therefore, Hypothesis 5 was not supported.

**Part 3: Post-hoc Analyses**

Because of the significant relation found between self-reported masculinity and internalized homophobia, ANCOVAs were conducted to discover if, after controlling for variance due to sex roles and homophobia, IPP would explain some of the variability in scores on the BSI. Table 4 provides a summary of adjusted means by IPP group and specific analyses are described next. A one way between-groups ANCOVA was conducted to determine if psychiatric distress (as measured by mean score on the BSI) was partially explained by IPP, after controlling for internalized homophobia. There was no significant difference between BSI scores [$F(2, 64) = 0.00, p = .999$].

Another one way between-groups ANCOVA was conducted to determine if psychiatric distress was related to IPP, after controlling for Bem masculinity scores. There was a significant difference between the three groups [$F(2, 64) = 3.87, p = .026$]. The mean
The study was designed to discover if anal intercourse position preference (IPP) for men who have sex with men (MSM) was related to sociodemographic characteristics, gender role orientation, and internalized homophobia, and whether gender role orientation and internalized homophobia were, in turn, related to psychiatric distress. In the first set of analyses, we noted few demographic differences among IPP groups. Bottoms were the least likely to be single, reported the fewest number of sexual partners in the last year (average of one), and had the lowest rates of condom use. It may be that, because they were in stable long-term relationships, bottoms reported lower condom use. Tops and versatiles were very similar in terms of frequency of condom use and number of past-year sexual partners (average of two). Other than those differences, groupings based on intercourse position preference had few statistical associations with demographic characteristics; sexual satisfaction, education level, annual income, alcohol use, and pornography use were not statistically significantly related to IPP. Taken together, it appears that IPP is not associated with most psychosocial variables. In fact, the only differences that emerged suggest bottoms report more stable, long-term relationships than tops and versatiles.

In our second set of analyses, we tested specific hypotheses about how IPP related to gender roles and psychological well-being. The first hypothesis (H1), which predicted tops and versatiles would endorse higher masculine traits than bottoms, received full statistical support. Indeed, in MSM, being the “penetrator” in a sexual encounter is associated with other self-described masculine characteristics, such as being a leader, an aggressor, and confident. This suggests that one way in which masculinity may be expressed by men is through their sexual behaviors.

However, our second hypothesis (H2), which predicted that versatiles and bottoms would endorse more feminine traits compared to tops, was rejected. Instead, both tops and versatiles endorsed high levels of femininity, while bottoms had lower levels of femininity. Overall, it appears that bottoms reported low endorsement of both masculine and feminine traits—seeing themselves as neither powerful or self-reliant nor compassionate or loyal. This may suggest bottoms have lower self-esteem than tops and versatiles, reporting fewer positive personality traits of any gender type. It is also possible that the Bem Sex Role Inventory’s items no longer adequately capture the domains of masculinity and femininity. As Hoffman & Borders (2001) suggest, it is possible that many of the gender-specific traits of 40 years ago are now seen as positive for everyone, regardless of gender. For instance, it may be that people are equally likely to see men and women as strong and independent, loyal and sensitive to others’ needs.

Our next set of analyses examined whether there were significant differences among the IPP groups on internalized homophobia and psychiatric distress. Hypothesis three (H3) predicted that internalized homophobia would be lower in versatiles and bottoms compared to tops; this hypothesis was fully supported. Given that being the “penetrator” in sexual relations is a behavior consistent with a masculine self-identity, it is not surprising that men who were less comfortable with their sexual orientation or felt less affiliation with the gay community also endorsed greater interest in and history of insertive anal sex. This is consistent with other work in MSM showing men who posted online advertisements seeking sexual encounters with non-gay-identified men were more likely to be looking

### Table 4. Study variables by intercourse position preference group, with adjusted means.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Top (n = 50)</th>
<th>Versatile (n = 28)</th>
<th>Bottom (n = 12)</th>
<th>F statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brief Symptom Inventory (adjusted for internalized homophobia)</td>
<td>0.48</td>
<td>0.38</td>
<td>0.64</td>
<td>$F(2, 64) = 0.00$, $p = .999$</td>
</tr>
<tr>
<td>Brief Symptom Inventory (adjusted for Bem Masculinity)</td>
<td>0.56</td>
<td>0.38</td>
<td>0.53</td>
<td>$F(2, 64) = 3.87$, $p = .026$</td>
</tr>
<tr>
<td>Brief Symptom Inventory (adjusted for Bem Femininity)</td>
<td>0.48</td>
<td>0.42</td>
<td>0.59</td>
<td>$F(2, 64) = 1.73$, $p = .186$</td>
</tr>
</tbody>
</table>

**Note.** Means sharing a letter in their superscript are not significantly different at the .05 level on Fisher LSD post-hoc tests.

BSI score for versatiles (0.38) was significantly lower than that of both tops (0.56) and bottoms (0.53). Tops and bottoms did not differ from one another. Finally, an ANCOVA examined if psychiatric distress was related to IPP after controlling for Bem femininity scores. The results were not significant [$F(2, 64) = 1.73$, $p = .186$].

**Discussion**

In our second set of analyses, we tested specific hypotheses about how IPP related to gender roles and psychological well-being. The first hypothesis (H1), which predicted tops and versatiles would endorse higher masculine traits than bottoms, received full statistical support. Indeed, in MSM, being the “penetrator” in a sexual encounter is associated with other self-described masculine characteristics, such as being a leader, an aggressor, and confident. This suggests that one way in which masculinity may be expressed by men is through their sexual behaviors.

However, our second hypothesis (H2), which predicted that versatiles and bottoms would endorse more feminine traits compared to tops, was rejected. Instead, both tops and versatiles endorsed high levels of femininity, while bottoms had lower levels of femininity. Overall, it appears that bottoms reported low endorsement of both masculine and feminine traits—seeing themselves as neither powerful or self-reliant nor compassionate or loyal. This may suggest bottoms have lower self-esteem than tops and versatiles, reporting fewer positive personality traits of any gender type. It is also possible that the Bem Sex Role Inventory’s items no longer adequately capture the domains of masculinity and femininity. As Hoffman & Borders (2001) suggest, it is possible that many of the gender-specific traits of 40 years ago are now seen as positive for everyone, regardless of gender. For instance, it may be that people are equally likely to see men and women as strong and independent, loyal and sensitive to others’ needs.

Our next set of analyses examined whether there were significant differences among the IPP groups on internalized homophobia and psychiatric distress. Hypothesis three (H3) predicted that internalized homophobia would be lower in versatiles and bottoms compared to tops; this hypothesis was fully supported. Given that being the “penetrator” in sexual relations is a behavior consistent with a masculine self-identity, it is not surprising that men who were less comfortable with their sexual orientation or felt less affiliation with the gay community also endorsed greater interest in and history of insertive anal sex. This is consistent with other work in MSM showing men who posted online advertisements seeking sexual encounters with non-gay-identified men were more likely to be looking
for a “masculine” partner who would penetrate them (i.e., a masculine top) (Downing & Schrimshaw, 2014). Presumably, these advertisements suggest that bottoms who desire a top partner recognize the ideal partner may have some internalized homophobia.

Finally, consistent with gender schema theory, we expected that both femininity (H4) and internalized homophobia (H5) would relate significantly to psychiatric distress. However, neither of these hypotheses was statistically supported. On the other hand, we found masculinity was significantly related to lower psychiatric distress. The findings of H4 and H5, when viewed in the context of hegemonic masculinity and patriarchy (see Connell, 2005), suggest that masculinity may serve as a protective factor against psychiatric distress in MSM. This is consistent with a large body of literature demonstrating the benefits of a more masculine gender role in both men and women (Bassoff & Glass, 1982; Cella et al., 2013; Cheng, 2005; Lefkowitz & Zeldow, 2006; Prakash et al., 2010; Taylor & Hall, 1982; Woodhill & Samuels, 2003). In particular, while having sex with other men may place a person’s masculinity in question, other traits can compensate for this. For example, MSM who are masculine in ways other than their sexual behavior (such as being aggressive, strong leaders, and analytical) can still reap many of the benefits of being perceived as a member of the powerful in-group of men. A more direct assessment of the potential discrimination faced by MSM who are more feminine and less masculine in their traits may help clarify the relations between gender roles and psychiatric distress we observed in the current study. In fact, one prior study suggested discrimination experiences mediate the relation between gender non-conformity and psychiatric distress (Sandfort et al., 2007).

We had originally anticipated IPP would relate to gender role orientation and internalized homophobia directly, and indirectly to psychiatric distress. Once we failed to find statistically significant associations between gender roles or homophobia and psychiatric distress, we explored whether IPP was directly related to psychiatric distress. Of note, the only analysis that found a relationship between these two variables was a post-hoc ANCOVA that controlled for masculinity. Findings suggest that versatiles had the best mental health of all groups, with tops and bottoms reporting similar (albeit low) psychiatric distress.

While the findings are preliminary, we think they warrant further investigation. For instance, perhaps versatile sexual behavior is comparable to an androgynous gender role orientation in that it allows for an expanded behavioral repertoire and flexibility in partnering decisions, where decisions about relationships can be made based on factors other than sexual compatibility. It may also be that a versatile identity is associated with other psychological variables, such as openness to experiences, which relate to positive mental health (Zoeterman & Wright, 2014).

Limitations and Future Directions

This study was novel in bringing together variables that had only been studied in relative isolation: anal intercourse position preference, internalized homophobia, gender roles, and psychiatric distress. The results largely conformed to expectations and revealed a possible benefit to being versatile in IPP for MSM, much as an androgynous gender role confers benefits on individuals (Prakash et al., 2010; Woodhill & Samuel, 2003).

However, the study’s strengths must be considered within the context of its limitations. Specifically, this study was limited by small sample size (n = 70) and being an internet-only self-report questionnaire study. In addition, the sample size was limiting in terms of IPP diversity. Furthermore, the compensation structure for participants changed as the study progressed because of difficulties obtaining participants. Although the number of bottoms in the study (19%) was close to established percentages in the other studies (21%) of MSM (Wei & Raymond, 2011), there were only 12 participants who were categorized as bottoms, limiting statistical power and sensitivity of analyses and generalizability of results.

In addition to addressing these methodological concerns, future research should explore potential variables that may explain the relations observed in this study. For instance, studies examining how discrimination experiences may mediate the relation between low masculinity and high psychiatric distress are warranted, as are studies that include assessment of personality characteristics that may relate to both sexual behavior (IPP) and mental health, such as openness to experience. One variable not well explored by this study was outness. Researchers (e.g., Scrimshaw et al., 2013) have found a relationship between being “out” versus “in the closet” and mental health, with outness associated with more positive
mental health. Furthermore, it may be that IPP changes as a function of outness. The major life changes that accompany the coming-out process (e.g., acceptance versus stigmatization, a change in social group) would be expected to have psychological impact. If IPP is a proxy for outness, it could be outness and its sequelae explain the relation between IPP and mental health. Future studies could also explore IPP in cultures outside of the United States and with larger samples of diverse racial and ethnic groups within the United States to determine if similar findings would occur in more diverse populations of MSM.

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Emergent Landscape: Urban Shadow Space, Illuminated

By: Hannah L. Hefner
Department of Landscape Architecture

Faculty Mentor: Phoebe M. Lickwar
Department of Landscape Architecture

Abstract

This study defines a new approach to the transformation of unmaintained land within cities, or urban shadow space. Although urban shadow space can offer a place of free expression for the community and spontaneous vegetative growth within a city, it is often dismissed as blighted land by public authority. This study maximizes existing opportunities of these spaces, illuminating a realm of the city that is currently dark to the public eye. A proposed set of guidelines is utilized in the creation of three alternative designs that illustrate the emergent landscape, a sensitively designed, evolving landscape that encourages user interaction with the site. These guidelines and the results of their application are intended to assist design professionals who wish to move beyond the typical “clean and green” strategy currently employed by many municipalities to embrace a site’s existing characteristics.

1. INTRODUCTION

Urban shadow spaces are abandoned, neglected and/or unmaintained plots of land within a city that feature deteriorating hardscape, spontaneous vegetative growth and evidence of human interaction with the site. These spaces are within city centers, yet lack the prescribed quality of typical city spaces and often are unruly. Lack of rigidly defined space means a changeable, ephemeral environment. This impermanence is evident in the vegetation, which grows unrestrained, the wildlife that finds habitat here, built materials that are allowed to decay, and user expression, which is not prevented. All of these elements interact, forming a complex system that functions in a unique way compared with typical city space that requires maintenance. Undisturbed vegetation grows unrestrained, providing habitat space for wildlife, carbon sequestration, a cooler microclimate, lots of shade, and distinctive seasonal change for a visually complex environment. Vegetation pushes through hardscape, such as concrete and asphalt, to create a state of rapid decay. Structures buckle, shed material and gain new openings for the passage of light, sound and wildlife. Unexpected mosaics emerge from new integrations of man-made and natural materials. Humans interact with this environment by manipulating it or being affected by it: they add to, subtract from, rearrange and experience the landscape. Culture and history accumulate in urban shadow spaces when people are free to express themselves and free to manipulate the environment in an un-prescribed, spontaneous way (Corbin 2).

Due to the site character or the inherent “wildness” of these spaces, people must adjust to these sites by engaging in a unique and personal way. The “Stalker Manifesto”, written by the anonymous urban explorer and marginal city land “steward, guide, and artist” known as ‘Stalker’, acknowledges a natural heightening of the senses in urban shadow spaces. In his book The Accidental Playground, Daniel Campo records an inventive mentality in nearly everyone he interviews and witnesses the site being programmed and reprogrammed based on the needs of the individual.

Many see urban shadow space as, “a model for public space in the city,” due to the site characteristics of these slowly evolving, engaging and functional spaces (Kamvasinou 255). This paper recognizes the positive aspects of Urban Shadow Spaces, analyzes them and attempts to operationalize them, or use the way they operate to inform a new design technique. The experience of spending time in urban shadow spaces is unlike inhabitation of any other kind of public city space. It reveals more about the reality of human presence in our environment than many highly maintained spaces could.

As cities develop, becoming more and more homogeneous, with large-scale designs imposed...
over the public realm (PHS Philadelphia LandCare), we forget the benefits of an unpredictable, evolving environment. “This basic human impulse- to shape and reshape, to arrange and rearrange, to destroy and rebuild- is not fully appreciated by architects, planners, and those who build and control the public spaces of American cities” (Campo 23). The “loosening of public space long controlled by the interests of governments, public authorities, property owners, banks, and corporations,” (Campo 29) has been demanded and wild urban landscapes have been supported by many voices over the past 50 years. Jane Jacobs argues for organic formation of cities in her book *The Death and Life of Great American Cities*. Lawrence Halprin outlines a way to involve community members in design in his book, *The RSVP Cycles*. James Corner expresses his theories on the importance of a complex, ephemeral, designed landscape through his design of New York’s *Highline*. Anna Jorgensen argues for use of urban shadow spaces to inform planning and design in her book, *Urban Wildscapes*. Peter Del Tredici lists the benefits of spontaneous growth in his book, *Wild Urban Plants of the Northeast*. Klaus Overmeyer, Philipp Oswalt, and Philipp Misselwitz present possible ways in which spontaneous site use can be incorporated into city planning in their book, *Urban Catalyst*. The set of design guidelines described in this study provides an answer to those calling for sensitivity, spontaneity and complexity. The result of the guidelines is an emergent landscape- a designed cultural landscape created through the input of individuals, a designer, and the processes of growth and decay.

2. BACKGROUND

Many urban shadow spaces are eventually developed, as in the case of the Brooklyn industrial waterfront in New York, the Nature-Park Südgelände in Berlin, the Landschaftspark Duisburg-Nord in Duisburg, and the Skulpturenpark in Berlin. Each of these designs was sensitively performed, taking inspiration from existing processes such as plant growth, hardscape deterioration and human interventions on site.

Other designers and city municipalities around the world have realized the opportunities of urban shadow spaces. These designers and municipalities have created design concepts from their observations of existing site functions and processes. It is through the designs of sensitive professionals that we can see successful attempts at preserving the site character and functionality of urban shadow spaces. Site sensitivity, a low level of intervention, the retention of visible layers of site history, and highlighting or accelerating natural processes occurring on site are all major elements of project designs that successfully preserve site character and encourage more and new forms of use on site.

Site sensitivity is essential when engaging an urban shadow space. These spaces have spent a significant amount of time out of the control of a governing body. Often, there is a reason for their neglect. In the case of Landschaftspark Duisburg-Nord in Germany, industrial ruins were left to decay when industry moved elsewhere. Thousands of local jobs were lost. The abandoned site became a symbol of economic decline, loss, and industrial contamination (Brown 68). Yet, the community was reluctant to forget this important cultural place. It was decided that a public park should be created from the remnants and Peter Latz was hired. He maintained cultural memory while initiating a healing process, preserving old remnants and creating new use for them. Latz took note of the vegetation spread that had occurred since Landschaftspark’s abandonment. He discovered that this important character-defining element was also functioning as a natural form of bio-remediation. Attention to existing process and allowing spontaneous growth to occur made it possible for inexpensive healing of the brownfield. Physically healing the site allows people to slowly recover from emotional distress (Keil 127).

Nature-Park Südgelände, in Berlin, Germany

Figure 1: The wave of foliage arching toward the open warehouse. Original work by the author, Hannah L. Hefner.
also required sensitivity due to public opposition to development (Langer 154). Designed by Odious Group, the park was abandoned and overgrown for many years, resulting in a huge urban forest in the middle of Berlin. Since the 70’s, the public has continuously used the land since its abandonment, so when development threatened, the people fought back to preserve the site as parkland. Because the public demanded that the site character and existing program be preserved, interventions on site are minimal. The design is based on the addition of raised metal trails and the preservation of existing railroad tracks, towers, and forest. Users are invited to explore the forest as before, but on strategically placed trails that reveal ruins, telling the story of the park. Industrial equipment is preserved in its found state of decay-steel rusts, thrown aside long ago. Graffiti persists on stone retaining walls and brick stations. Trees grow between rail tracks, in the midst of a forest in what was previously their habitat. The process of a forest growing in place of a rail yard is revealed to users by inviting them to walk over exposed train tracks and between trees that grow through the tracks.

Urban shadow space characteristically includes small interventions performed by individuals who use the space. These include temporary artworks, such as those in the Skulpturenpark of Berlin, dwellings, and community gardens. The Albany Bulb in Albany, California and the pre-development Brooklyn Industrial Waterfront in Brooklyn, New York are true, functioning urban shadow spaces within their respective cities. These sites serve as the places for the homeless to make their home within the city, free exhibition space for artistic expression, and recreational destinations for local residents and tourists.

Skulpturenpark in Berlin, Germany, managed by the art collective ‘KUNSTrePUBLIK’ is a landscape of temporary art installations that often use existing site material and spatial qualities to inspire each artwork. A pile of existing rubble seems undesigned and unmaintained. A stream of water mysteriously falls from the top of the pile and a light comes from within it providing enough intervention to suggest intentional placement and care for the site. This sensitive approach is respectful of the site’s past life as a no man’s land next to the Berlin Wall and then as an urban shadow space. Here, the urban shadow space and existing park are forms of emotional remediation. Users contemplate the oppression of the Berlin Wall as they begin to associate new meaning and freedom to the site through the viewing of art installations.

The Albany Bulb features low cost, low intervention techniques employed by those who have taken ownership of the space. Visitors have made soft trails, artists have transformed concrete rubble into sculptures and canvas space for colorful murals, and the homeless have built small homesteads out of recycled materials found on site. The Brooklyn Industrial waterfront similarly functioned as a destination for artists, the local community and the homeless. The site enabled them all to have influence over land- a rare opportunity in such a dense city.

Adapting on-site material to a new use works well for places like the Albany Bulb and the Brooklyn

Figure 2: Trees growing between the tracks at Naturpark Südgelände. “Creative Commons Naturpark Südgelände.” Original work by Sebastian Michalke used under CC BY 2.0: http://creativecommons.org/licenses/by/4.0/ Source: www.flickr.com

Figure 3: A sculpture made from discarded materials at the Albany Bulb. “Creative Commons Cavalry.” Original work by Nathan Jongewaard used under CC BY 2.0: https://creativecommons.org/licenses/by/2.0/legalcode Source: www.flickr.com
waterfront that were, in recent history, trash dumps. This method is used as an inspirational tool for artists at Skulpturenpark. Alternatively, recycled material from offsite could be added to an urban shadow space as a way to avoid waste. The Adventure Playground of Berkeley, California uses donated lumber and other building materials for a unique play experience for children. In this park, children are invited to create their own program on site by building structures themselves with real tools. The idea is that a bit of danger and risk taking while building and problem solving is valuable to a child’s development. Each site is able to preserve or enhance site character by preserving physical objects on site, even if the material is initially seen as waste.

When a site is not prevented from transforming and interventions are not removed or covered over, a complex and visible set of layers forms on the land. The landscape is thought provoking. The user is compelled to distinguish layers and separate them into different time periods and past site uses. In both Landschaftspark and Nature-Park Südgelände, the transition of industrial wasteland to park is evident; there are indicators of the way these places passed through time. The user can imagine the coal and steel production plant and the train station in their productive state and can see roughly how long the sites have been left to natural processes by determining how old the vegetation is that grows in the ruins. Leaving materials on site and allowing the designer to make only minimal interventions can allow this visible history to remain in the designed urban shadow space.

The Skulpturenpark artworks draw awareness to processes on site. With each small intervention, the artist is asking for the user’s attention to a piece of the site. By examining the artwork, the user will observe rubble, cleared land and tree-filled land, spontaneous vegetation covering ruins. It is natural for the user to ask questions about the space as the artist highlights various elements of the site. Even if questions remain, this is how people are made aware of the history, the passage of time through this space.

3. URBAN SHADOWS LOST

Urban shadow spaces are historically misunderstood and systematically wiped clean to make way for insensitive design. They are invisible to some, shadowed between buildings in alleyways, overlooked due to their absence of formality and tendency to change. When they are made visible, their demise is usually forthcoming. They are seen as vacant, dangerous, unclean, blighted, and unruly. Shadow spaces are neglected, left to their own devices. The owner, if there is one, has abandoned the responsibility of maintenance so the site appears to be unwanted. Designers are called to these “unwanted” sites with a particular goal: to make corrections to a broken landscape, to sterilize the site, and to fix problems at the cost of demolishing an existing cultural repository, carbon sink, and timeline expressed in landscape (Corbin 12; Del Tredici 308).

The City of Philadelphia’s “Clean & Green” program consists of “removing all debris and weedy vegetation, grading, adding compost enriched topsoil, and planting grass and trees to create park-like settings. A signature post and rail fence defines the land as a cared for property. After improvements are completed, the sites are regularly cleaned and mowed” (PHS Philadelphia LandCare). This formulaic response to the problems associated with urban shadow space is an effective solution if a safer environment is all that is desired of the space. What is lost is a site defined by individuality of place, authenticity, and evident evolution through time at the very least.

What other benefits does this solution offer the community? It offers the neighborhoods increased property value and lower crime, but there’s a chance that increased property values are lowering crime by gentrifying the area (Lees, Slater, and Wyly). These are not sustainable sites if energy must be used to constantly mow them during the growing season. They restrict access with a fence, therefore taking usable land away from the surrounding community. These new spaces are of the same aesthetic—this does not provide for diversity of a population. What if these sites did not require so much maintenance, served as creative centers for individuals within the surrounding neighborhoods, and were still “defined as cared for properties”? An alternative like this could be a valuable addition to a neighborhood.

Even designers who see opportunity in shadow spaces have failed to preserve important site characteristics. The High Line project by James Corner Field Operations is directly inspired by the urban shadow space from which it came. The original highline was composed of spontaneous growth between rusted railroad tracks, peacefully removed
from the rest of New York City, floating above the city as a self-regulating, thriving ecosystem. When its demolition was nigh, the “Friends of the High Line” assembled to save the highline by transforming it into a public park. The winning design by James Corner Field Operations imagined a park that “is designed to remain perpetually unfinished, sustaining emergent growth and change over time” (James Corner Field Operations). Upon visiting however, it is clear that the new space is highly maintained and refined. The original vegetation has been removed and replaced with planted vegetation. Unmoving, permanent concrete modules may evoke the aesthetic of concrete being slowly overtaken by vegetation but the forms are contrived, built to withstand change by vegetative means. The landscape is static despite the intention to create a landscape that evolves with time.

The Brooklyn Industrial Waterfront, analyzed for its successful functionality by Daniel Campo in his book *The Accidental Playground*, was claimed by the state of New York to be transformed into a formalized park. State Parks developers were interested in Campo’s suggestions. He recommended that they “leave the landscape more or less as is”. State Parks tried to balance Campo’s suggestion with the values of other stakeholders, producing an “incremental, still evolving” site with an open-ended future, but “the playfulness of the state’s ‘in place’ design had not been matched with an accordingly flexible or liberal administrative policy” (Campo 226).

The effect of this was a dramatic demographic switch from those that used the Brooklyn Industrial Waterfront in its state of wildness to new residents of condos built next to the newly completed state park. New rules formed out of fear of litigation and safety regulations limited the time of day people are allowed in the park and what people can do in the park. This has compromised some of the most important site characteristics. For example, loose materials have been removed when before, people had materials to create with on site. Dogs are no longer allowed even though dog walking was a primary use of the site before it became a park. Waterfront access is now limited. Much of the vegetation has been removed- an important physical and spatial characteristic before.

This case study shows that it is not enough to simply make a park that is aesthetically similar to an urban shadow space. Preserving elements of an urban shadow space destroys existing site character and unique uses of a more spontaneous landscape.

These projects generally do not fail due to lack of functionality. The Clean and Green Program creates safer areas and the High Line project provides a beautifully designed and unique vantage point in New York City. Each project though, has the unintended result of loss of character when designing should preserve and enhance site character. Designing urban shadow spaces without destroying them will first require a shifted mindset. Instead of being seen as derelict land in need of beautification, designers must see them as an opportunity to embrace existing dynamics of nature and culture.

4. METHODOLOGY

This research utilized a methodology in three parts: 1) analysis of urban shadow space; 2) formation of a set of guidelines; and 3) testing of the guidelines through the production of three design alternatives for an urban shadow space.

5. ANALYSIS OF URBAN SHADOW SPACE

The author preformed surveys to record distinctive characteristics of urban shadow space. Three urban shadow spaces were analyzed for their physical and cultural features, as observed by the author on the grounds during site visits. These experiential features of urban shadow spaces shape the user’s perceptions, creating a strong identity for the site. The character defining elements are articulated in the following chart:
The character-defining elements (listed in the above chart) were recorded qualitatively on site as written descriptions, photographs, maps, sections, and other informative sketches of the site. The rough data and notes taken on site were graphically represented and layered on maps. The process was influenced by landscape architects such as Randolph Hester and Lawrence Halprin who both developed methods of recording experience on paper (Hester 86). Phenomenological processes, or unseen processes, were recorded and expressed visually through the same technique. For example, elements like “defined spaces” were represented on the site analysis map as delineated fields and “site affect” was represented through colors or symbols associated with emotions felt on site. With all of the character-defining elements layered on paper, the interactions between elements were mapped through layers that overlap. Intersecting or overlapping layers on the site analysis map were interpreted as areas of experiential complexity.

Recording the character defining elements and subsequently combining them into a site analysis map influenced the formation of the guidelines by indicating the experientially complex areas of the urban shadow space. These areas were compared with similar areas in the case studies described in the “introduction” and “background” section of this paper. Design techniques employing cost efficiency, a low level of intervention, or public engagement (such as the use of existing, on-site materials as mentioned in the guidelines) were extracted from the case studies and directly added to the guidelines. Site elements that were added, subtracted, or preserved in the designs of the case studies were also directly translated to the guidelines when they met the cost, intervention level and engagement requirements of this project.

The guidelines take inspiration from projects mentioned throughout this paper. Specifically, the guidelines encourage the design professional using them to employ techniques exhibited in the case studies to design an emergent landscape. The minimal interventions performed at Nature-Park Südgelände, the Landschaftspark Duisburg-Nord, and the Skulpturenpark is a continuous theme in the guidelines. Spontaneous growth is proven worthwhile and cost-effective at Duisburg-Nord and by Emma Marris in her book Rambunctious Garden- unrestrained growth is versatile design device repeated in the guidelines. The guidelines encourage design performed by

Many of these characteristics recorded are typically part of site analysis diagrams used by landscape architects before designing any space. “Site affect” and narratives are atypical characteristics found on site for this study. These atypical characteristics gather information that is intuitively seen and felt on site in order to imagine the experience of a site user.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
<th>Examples in context of this study</th>
</tr>
</thead>
<tbody>
<tr>
<td>entry</td>
<td>The portal through which users most frequently access the site. Entries are often indicated by trampled earth and proximity to designated pedestrian paths.</td>
<td>Entries, such as a tunnel of bamboo, can help inform site circulation.</td>
</tr>
<tr>
<td>defined spaces</td>
<td>Spaces such as rooms or corridors within the site defined by vegetation, structures, or other implied boundaries.</td>
<td>Attention to existing spaces can inform sensitive designation of new spaces.</td>
</tr>
<tr>
<td>topography</td>
<td>Grade change; recorded with contour lines.</td>
<td>Topography is instrumental in creating spaces, guiding the flow of water, and guiding the movement of living things throughout the sites in this study.</td>
</tr>
<tr>
<td>spatial organization</td>
<td>How defined spaces are connected through physical or sensory means.</td>
<td>This interconnection of spaces helps the site function as a cohesive unit.</td>
</tr>
<tr>
<td>circulation</td>
<td>Existing human and animal movement through the site.</td>
<td>Paths are often defined by trampled earth, also known as desire lines. Observe circulation informs designed circulation.</td>
</tr>
<tr>
<td>past &amp; present site uses</td>
<td>Perceived site uses. Visible history of plant succession, human &amp; animal occupation, structure existence, etc.</td>
<td>Site uses are usually highly visible in urban shadow space, and therefore worth noting for their ability to preserve identity and cultural value</td>
</tr>
<tr>
<td>animal presence</td>
<td>Species evident or seen and potential habitat.</td>
<td>Disregarding the existing habitat and species could disrupt the ecology and affect the character of the site.</td>
</tr>
<tr>
<td>existing structures &amp; remnants</td>
<td>Man-made objects such as buildings, walls, foundations or ruins.</td>
<td>Remnants and structures contribute to site character and should be preserved.</td>
</tr>
<tr>
<td>state of deterioration</td>
<td>Descriptions of time-based changes of man-made and organic materials on site including the general date of last maintenance.</td>
<td>Deterioration is often undervalued in city space. However, features such as rusting metal, cracking concrete, decaying pine needles, etc, can allow users to experience the process of life, death and impermanence in landscape.</td>
</tr>
<tr>
<td>state of growth</td>
<td>General age of vegetation and growth patterns.</td>
<td>Spontaneous vegetation contributes to the ecological health of the site while shaping physical space and user experience.</td>
</tr>
<tr>
<td>site affect</td>
<td>Sensory/emotional climate associated with the site.</td>
<td>Unique, pleasant or defining site affect leads to preservation of physical elements associated with those feelings.</td>
</tr>
<tr>
<td>narratives</td>
<td>Plot lines, real or perceived, generated through the interpretation of objects found on site.</td>
<td>Stories inspired by one’s experience on site can influence an imaginative design.</td>
</tr>
</tbody>
</table>

Figure 4: An example of an analysis map, layered with recorded site characteristics. Original work by the author.
designers and site users - this is influenced by Jane Jacob’s support of the organic formation of cities, by Lawrence Halprin and Randolph Hester’s involvement of community members in designing, and by the Skulpturenpark, which is designed by a team that involves site-specific installations by many artists. The allowance of layers of artifacts to collect on site in an emergent landscape is inspired by the cultural landscapes of the Albany Bulb and the Brooklyn Industrial Waterfront. On-site creative expression through the use of leftover, loose material is shown at the Berkeley Adventure Playground, the Albany Bulb, and at the Brooklyn Industrial Waterfront. Each of these ideas is adapted, in the form of guidelines, to design an emergent landscape below.

6. GUIDELINES

A series of guidelines, listed below, was created to help design professionals in any city design sensitively enough to maintain and enhance the existing cultural imprint and site character of an urban shadow space, encourage transformative design, promote increased community expression on site, permit decay, increase vegetative growth and create an unpredictable outcome that will be of greater complexity than the designer can anticipate. The result of the guidelines is an emergent landscape.

Perform a thorough site inventory & analysis
- Record character-defining elements and combine them into a site analysis map (a character-defining elements chart is located in the “Analysis of Urban Shadow Space” section of this paper).
- Take inventory with the goal of recognizing the urban shadow space as a complex environment worthy of being treated with sensitivity.
- The site analysis process will help the designer in her responsibility of defining a relationship with the site and determining what needs to be preserved or enhanced while employing the guidelines.

Gain community support
- Identify potential stakeholders within the community.
- Negotiate legal limits with the local city government- some progressive cities are willing to bend the rules if a proposal will become a community asset (Weiderholt).
- Find or create a non-profit organization to provide minimal maintenance and take liability responsibility.
- If the urban shadow space is on private property, negotiate with the property owner. A semi-maintained & publicly accessible site supported by an organization may be desirable for the landowner if he is not able to maintain the land himself or is particularly receptive to the idea (KUNSTRePUBLIK 26).

Form a relationship with the site to understand phenomenological aspects
- Phenomenological features are parts of a landscape that affect the experience of an individual, but are not physical things, such as the scale of the site (Corner 245). Scale, for example, is a phenomenon that humans perceive by comparing the scale of the landscape against their own perceived scale. Because these phenomena are not manifested physically, a designer must investigate a site further to discover them.
- The designer’s job is mostly to recognize processes that are already happening in these spaces, or what is special about the existing state of urban shadow spaces.
- The designer should intervene enough to amplify the unique physical and phenomenological qualities of the existing space.
- The designer must explore the site herself to be able to think like a site user and fully understand the effect of the urban shadow space. It’s okay to design based on personal experience and personal thought processes that occurred on site in order to create a design that is sensitive enough to accurately amplify phenomenological characteristics of the site.

Trying to imagine past scenarios on site was a way for the author to personally connect with the site and ultimately produce a design that provokes an imaginative response in the user of an emergent landscape.

See existing processes & physical aspects as design opportunities
- Where there is an area of some existing spatial definition, add plantings or screens or structures to further define the space.
• When a space is an inappropriately large scale, vegetation, walls, and/or overhead structures should be added to subdivide space.
• Existing failing structures that provide important spatial definition should be reinforced.
• Consider including on-site, man-made objects in the design—even if they are small or seem insignificant, like a pile of bricks.
• Preserve even deteriorating objects.
• Some impermanent objects on site can be removed & replaced with designed structures that can provide equal spatial presence and somehow acknowledge the past object.

Illuminate processes
• Illuminate processes observed on site through design.
• Accelerating the decay of site features can make the process more apparent.
• Building something new from existing site materials can inspire questions.
• Adding subtle indicators of the past site use can make the user more aware of the site’s progression through time.

Allow users to develop the program
• The designer can develop program for the site, but the expression of the program on site should not be obvious to the user and should be changeable by the user and open to interpretation by the user. The user should have to decide for him/herself what the spatial uses are.

Design for phasing & change
• The designer can anticipate and plan for simultaneous growth, decay and human intervention on site (e.g. Create a maze of underground bounds for bamboo; plan the destruction of a paved area caused by spontaneous growth, then have a plan for what to do with the broken concrete. Anticipate graffiti and cover it from time to time with paint. Covering graffiti with paint is also a form of creative expression).

Use a sensitive, low-intervention, low-cost approach
• The intervention should be the smallest possible in order to preserve existing site character.

Expect little or no maintenance

• Turf grass (that requires mowing) should be limited or avoided. If a lawn is planned, the design should be able to function if the turf grass is not maintained. The designer should anticipate tall grass mixed with other plant species.
• Materials should be creatively re-used on site in the design or left in place.
• Leave objects in their original place when appropriate for users to make guesses about past site uses.
• Recycle/reuse existing on-site materials. Example: break up concrete from an unused parking lot on site. Use the pieces for a new path.
• Use materials as spatial defining features or sculptural features when possible.
• Maintain site mystery, thought provoking qualities, and character defining traits of the site.
• Sensitivity to existing detail is required.

Relinquish control
• Allow users to manipulate the design.
• Plants should be allowed to express their power and resilience in an emergent landscape. Allow plants to break down hardscape as a show of the temporary nature of human-built structures.

Expect creative expression of many forms by users
• Leave materials on site that the user may build with.
• Provide artist ‘canvases’ (e.g. blank walls & expect murals to appear there).

Figure 5: Graffiti is a highly varied form of user expression. Original work by the author, Hannah L. Hefner
Expect Decay
- Integrate further decay of site objects into the design.
- Initiate decay of structures or hardscape for a process-based design (perhaps by planting fast growing, resilient trees at a concrete foundation to break the foundation with time).
- Impermanence is a character-defining trait of urban shadow space.

Expect Growth
- Plantings should generally be allowed freedom to spread and dead foliage generally should not be removed (with the exception of invasive species such as bamboo, whose spreading should be controlled in some way).
- Expect the design to grow more complex over time as more individuals intervene on site.

7. DESIGN ALTERNATIVES

The shadow site used for the design experiments is a cluster of three lots in Fayetteville, Arkansas on Prairie Street in a former industrial district. Since the original existence of an animal feed mill, three houses were demolished, leaving only concrete and stone building foundations. The buildings’ foundations are in a state of decay- cracks permeate the slabs and spontaneous vegetation grows through them. Graffiti is located on the inner walls of the building foundations and possesses a particularly nonthreatening aesthetic. The lots await purchase.

Three design experiments incorporate the guidelines to express a variety of ways they may be implemented. The design process was used as the method for testing and revising the design guidelines. Each design serves as an alternative low intervention approach, applied to the same shadow space.

“Infectious Installation”

Due to the ease of assembly, unrefined aesthetic and availability of loose parts, pedestrians on the bike trail, neighborhood residents or other community members are invited and persuaded to create their own rock cairn, or balanced stack of rocks, on site. This simple program element requires exploration of the site to find construction materials, time on site for construction, and creative expression through the formation of the individual rock stack. Rock cairns will continue to appear on site, installed by many users.

“Accelerated Decay”

Removed slabs of concrete begin to crumble through natural processes over time. Attention is drawn to the concrete slabs by the removal and replacement on site. As users continue to visit the site over time, they will notice the gradual crumbling of the concrete and be reminded of the impermanence and vulnerability of the human realm. The void spaces created in the existing building foundations can be claimed by individuals for varying uses. Some may become sand boxes or installation space for something unexpected and eye-catching.

“Historic Reference”

Through site material choice and the addition of an interactive, sculptural structure, past and present uses are alluded to. Wheat and a climbable tower hint at the site’s past occupation by an animal feed mill. The present state of overgrowth is referenced by the use of lush bamboo and spontaneous growth. These symbols are meant to be ambiguous and confusing to further complicate the user’s thought process on site and allow the user to add personal meaning to the...

implementation of the guidelines

Many of the techniques below are inspired by the ideas in the book Urban Catalyst, which discusses ways to implement temporary use on an underused site and the creators of Skulpturenpark in Berlin, who negotiated with many private landowners in order to create a sculpture park in underused space.

A city government may be interested in hiring a design professional to design emergent landscapes if:

- There is current occupation and use of the space by city residents.
- There is not enough funding for the development of a formalized park.
- There is an overabundance of shadow spaces within a city; this may affect walkability or be associated with crime.
- There is city government interest in a transitional space or a landscape reflective of the needs of the surrounding community.

A private property owner may be interested in hiring a design professional to design an emergent landscape if:

- There is current occupation and use of the space by city residents.
- The owner is “sitting” on property without the funds or time to maintain it.
- The owner wants to develop according to the program that the population creates in the emergent landscape.
- The owner would like to increase the value of the property through design.
- The owner is interested in donating the property, permanently or temporarily, to the public.

9. DISCUSSION

Site character is dependent on innumerable factors, making it impossible to record them
all during the site analysis process. This paper assumes that it is possible to record and maintain enough site characteristics throughout the design and implementation processes to preserve existing character and user interactions with the site according to the sensitivity exhibited in the precedent studies discussed in the “Background” section of this paper.

Due to the open-ended nature of the guidelines, misuse or misinterpretation is a risk. The guidelines are a reflection of the design professional and are interpreted based on his or her intuition, experience and skill. A landscape architecture student trained in site sensitivity has written this study, so it is not known if other design professionals have the background necessary to design an emergent landscape. Being site-sensitive requires a designer to have practiced becoming aware of processes in the environment through observation. The designer could use techniques such as landscape photography, landscape drawing, landscape painting, gardening, or exploring to notice more processes on site and then be able to acknowledge them in the design.

If an emergent landscape were built in a place where the surrounding community is unreceptive to it, the space could become underused or dangerous. Engagement with the local community is crucial before installing this type of landscape.

One person, the author of this research, created the guidelines and performed three design experiments on only one site. The study cannot prove that the guidelines can be applied to varying contexts or be used by other designers until other designers, in other varying places, continue the experiment.

10. IMPLICATIONS FOR FUTURE RESEARCH

The guidelines are designed to serve all urban shadow spaces equally because no site is entirely vacant, however, some urban shadow spaces make better candidates than others. Therefore, guidelines on choosing an appropriate urban shadow space may be a valuable addition to this paper. This could include a guide to engaging the community before installing an emergent landscape.

Allowing the design experiments to be performed by multiple design professionals would show true variability of design and prove the strength of the guidelines. Also, guidelines could be written by multiple design professionals to prove the strength of the existing guidelines and provide valuable amendments. Allowing other designers and non-designers such as gardeners, artists, city planners and community members to participate using the guidelines could show the adaptability or the possible scale of the future impact of implementation of the guidelines across the country.

The evaluation of an implemented emergent landscape is a compelling next step for the research. An emergent landscape designed with the guidelines should be evaluated based on the perceived change in site character and the amount of user expression on site. The evolution of the site should be recorded over time to see if the desired effects of the guidelines are sustainable.

CONCLUSION

Urban shadow spaces have long functioned as complex sites layered with culture, untamed growth, decay, and free expression. These processes will exist for each site, until they are misinterpreted as blighted land and eradicated. In order for cities to view the benefits of urban shadow space, there must be a middle ground.

The emergent landscape can serve as a way to communicate to city authority and the public by showing the results of a land designated, designed, and open for free expression, spontaneous use, growth, and decay. City officials can use the newly visible land to begin employing these methods of sensitivity throughout the realm of public space. Using the guidelines as a tool, design professionals can efficiently design urban shadow spaces with sensitivity and flexibility according to their interpretation of the site. If the guidelines are employed, spontaneous growth and spontaneous interventions may gain respect for their benefits to an urban environment and city residents will see a new addition to the realm of public space that is open to their creative influence.

This study opens urban shadow spaces to interpretation and manipulation by all to create an unpredictable outcome. The resulting landscape, made with the guidelines, should be open to as much interpretation as the guidelines themselves. Emergent landscape is an experiment ground: a space in which plants, animals, humans and natural processes contribute elements to form one design. Let the layers of information found in an emergent landscape
inspire design professionals to move toward sensitive, engaging design in cities.

WORKS CITED


A New Design Method for Vanadium Redox Batteries in Renewable Energy Systems

By: Casey Gibson
Department of Biological Engineering
and
Karla G. Morrissey
Department of Chemical Engineering

Faculty Mentor: Roy McCann Ph.D.
Department of Electrical Engineering

Abstract
This study investigated the behavior of vanadium redox flow batteries (VRFBs), which are batteries capable of easily switching between charging and discharging modes, making them a suitable option for storing intermittent sources of alternative energies (solar, wind, etc). Since different sizes of the battery provide varying voltages, optimal parameters for a particular home are key for implementation. These parameters, specifically the cell and tank volumes of the battery that are capable of providing consistent on-load voltage, were determined using data from a 13 kW solar array and a medium-sized house. Charge/discharge current values were used to run a mathematical model that provided on-load voltage over time graphs based on parameter input values. Using this model, the optimal parameter values were found to be 11.5 L for the cell volume and 103.7 L for the tank volume, which maintained the on-load voltage well above 0.80 V (10% of cell standard emf).

Introduction
Since their invention in the 1980s, vanadium redox flow batteries have shown beneficial properties, such as high energy efficiencies, long life cycles, and controllable energy capacities that are crucial for the ongoing effort to store intermittent energy sources such as wind and solar energy (Xie, 2011). Redox flow batteries are rechargeable and contain two separate tanks of liquid electrolyte material separated by an ion-exchange membrane (Rychcik & Skyllas-Kazacos, 1988). On either side, there are tanks of negatively and positively charged chemical substances that undergo redox (reduction-oxidation) reactions, in which electrons are transferred between substances. The oxidation number of a substance denotes the charge, and by finding the oxidation numbers of elements before and after reactions, it can be determined whether electrons were lost or gained, and the flow of electrons through the battery cell generates electricity.

Specifically, vanadium redox batteries were studied for this project. On the positive side of the battery, vanadium is found in the states: VO$_2^+$/VO$_2^{2+}$, while it is found as V$^{2+}$/V$^{3+}$ at the negative electrode (Xie, 2011). While the battery is charging, VO$_2^{2+}$ is oxidized (loses electrons) to become VO$_2^+$, and V$^{3+}$ is reduced (gains electrons) to become V$^{2+}$, shown by equations (1) and (2) below. The opposite reactions occur while the battery is discharging:

1) Positive Electrode:
   \[ \text{VO}_2^{2+} + \text{H}_2\text{O} - \text{e}^- \rightarrow \text{VO}_2^+ + 2 \text{H}^+ \]
2) Negative Electrode:
   \[ \text{V}^{3+} + \text{e}^- \rightarrow \text{V}^{2+} \]

This particular type of flow battery can easily be upsized or downsized based on demand, simply by increasing or decreasing the size of the battery or the amount of vanadium electrolyte material (U.S. Patent No. 6,764,789, 2004). Additionally, this battery is very stable because of its ability to quickly respond to changes in battery load; essentially, it bridges the gap between energy supply and demand (Xie, 2011). As a result, vanadium redox batteries are promising for use with inconsistent energy sources such as solar panels.

To illustrate, the battery will store energy while the sun is out, but it will discharge when the sun is obscured or during nighttime. However, because of the delicacy of designing an optimal ion-transport membrane found in the cells, these batteries have not been commercialized (Chen, Hickner, Agar, & Kumber, 2013). In the
meantime, more research is needed on mathematically characterizing the behavior of VRFBs. Mathematical models allow for further understanding of the VRFBs and how to best implement them in electrical systems.

Over the last few decades, renewable energy from solar, wind, hydroelectric, and other sources have been researched and employed throughout the world, yet energy demands are not being met and instead are rapidly increasing, expecting to double by 2050 (Yang et al., 2010). As copious advances continue to be made in renewable energy technologies, some researchers are investigating how to store this energy for later consumption. Energy generated from natural sources such as wind and the sun are highly susceptible to local weather patterns, creating periods of large energy generation and almost zero generation, such as nighttime in terms of solar energy (Shwartz, 2013). Renewable energy is therefore not only unreliable during certain periods, but also limited in conditions when more energy is being produced than is being consumed.

Consequently, this problem has called for a deep investigation towards technology that can store excess energy, particularly in the form of electrochemical storage in batteries which can be used during peak hours when energy generation cannot meet the demand (Resch, 2013). These batteries include lead-acid, lithium-ion, sodium-sulfur, and particularly vanadium redox flow batteries. Vanadium redox flow batteries are relatively newer than the others, therefore still require much research. However, they show promising qualities in that they are less reactive and prone to combustion than sodium-sulfur batteries, and they withstand frequent charge/discharge cycles better than lead-acid batteries.

While VRFBs could potentially increase the use of renewable energy, incorporating alternative energy sources with storage batteries has some disadvantages. For example, there are concerns about increased emissions due to power plant cycling to compensate for fluctuations in renewable energy sources. These fossil fuel plants are designed carefully to minimize emissions under constant power conditions. Also, generators might exhibit premature failure of components because of exposure to the thermal and pressure-related stresses of cycling. However, a study conducted by the National Renewable Energy Laboratory demonstrated that the negative cycling effects were negligible in comparison to the reductions of CO$_2$, NO$_x$, and SO$_2$ emissions resulting from the use of alternative energy (NREL, 2013). In fact, net carbon emissions were reduced by one third.

Thus, a primary step in designing an electric power grid using vanadium redox batteries is to develop mathematical models based on the reaction kinetics and efficiency in real-time, particularly in residential settings. These models can be used to predict their efficiency and reliability when incorporated into the electric power grid. As a result, in the near future it could be possible to make homes more autonomous from the public electric grids with personal solar panels connected to vanadium redox batteries (Resch, 2013). By mathematically optimizing variables like tank volume and battery cell size, vanadium electric grids can be tailored to meet the specific energy demands of a consumer while reducing reliance on the electric power grid. Quantified validation of the potential success of vanadium redox batteries in renewable energy systems will make actual implementation closer to reality.

Characterization of Generation and Electrical Load

The first objective was to use power generation data from an installed PV system (solar panels installed at the Fayetteville Public Library) and power consumption data from a household to determine $x_e$, or the charge/discharge current of the battery. SolrenView, a data website from the company, Solectria, was used to find the power generated in kilowatts for a particular day (August 2, 2013) chosen specifically because of its greatly varying measurements of energy generated throughout the day (SolrenView, 2013). Note, this graph (Figure 1) shows the power generated scaled up by a factor of 3.5 so that the power generated by the solar panels roughly equaled the power consumed by the household. The household data was collected from the Southwestern Electric Power Company (SWEPCO), which used a General Electric “Smartmeter” to record the average power being consumed at one minute intervals (SWEPCO, 2013). These values are graphed in Figure 1.

As shown in Figure 1, the energy generated by the solar panels varies significantly throughout the day, generating zero power until 7 am, and then reaching peaks of power generation around mid-
morning, mid-afternoon, and early evening. The data from the family household gave insight into the peak energy usage hours for a typical family and how these hours differ from times of optimal solar power generation. For example, solar energy was most available in the afternoon, but electricity usage peaked in the evening. The variable, $x_3$, was found by taking the average power generated, $P_{Gen}$, by the PV system at five minute increments, subtracting the average power consumed, $P_{Con}$, by the household, and dividing by the standard voltage for house outlets, 120 V. The charge/discharge current (Figure 2) for an overall two-day cycle was found using equation (3).

$$x_3 = \frac{P_{Gen} - P_{Con}}{120V}$$

### Analysis and Modelling of VRFB

The next objective was to characterize the behavior of the VRFB using a mathematical model.

The mathematical model was developed using the following four equations (Minghua & Hikihara, 2008). Table 1 lists the variables, parameters, and constants included in the equations used to derive the mathematical model.

(4) $$\frac{d^2x_1}{dt^2} + W_0 \left( \frac{1}{\mu_1} + \frac{1}{\mu_2} \right) \frac{dx_1}{dt} + \frac{1}{\mu_1 F} \frac{dx_3}{dt} + \frac{W_0}{\mu_1 \mu_2} x_3 = 0$$

(5) $$\frac{dx_2}{dt} + \frac{1}{\mu_2} \left( \frac{\mu_2}{\mu_1} + \mu_2 \right) + \frac{x_3}{F} = 0$$

(6) $$x_4 = E_e^0 + \frac{2RT}{F} \ln \frac{x_1}{x_3 - x_1}$$

(7) $$x_5 = x_4 - x_3 \left( \mu_4 + \mu_5 \right)$$

Equation (4) shows the relationship between the design parameters, $\mu_1$, $\mu_2$, and $W_0$, and $x_3$, which is the concentration of $V^{2+}$ in the cell at a constant flow rate. The forcing equation is depicted by the last two terms that contain $x_3$. Equation (5) relates the concentration of $V^{2+}$ in the tank to the concentration in the cell and the charging/discharging current. The no-load voltage, $x_4$, given by equation (6) gives the voltage of the battery when there is no energy demand. Equation (7) accounts for the load resistance and impedance of the battery when there is energy demand to give the on-load voltage, $x_5$. A mathematical model was developed using MATLAB, shown in Figure 3, incorporating equations (4), (6), and (7) and the values calculated.
for $x_j$ to find $x_j$, or the on-load voltage.

The charge/discharge current found from the first objective was used to run the simulator and derive a graph of the on-load voltage over time depending on the different values used for cell and tank volumes at a constant flow rate.

Verification of the Model

To verify the model (third objective), the simulator was set at the experimental values of the design parameters, $\mu_1$ and $\mu_2$, and this graph was compared to the experimental results shown in Figure 4. The parameters for the model were set as follows: 0.100 L for the cell volume, 0.900 L for the tank volume, and a constant 3.5/12 L/min for the flow rate. These values equaled the cell and tank volumes used for the experiment with the small-scale VRFB, totaling 0.987 L for cell and tank volumes. After running the mathematical model, the theoretical on-load voltage graph set at the experimental parameter values was produced. Figure 4 and 5 were then compared to find the validity of the model.

These results shown in Figure 4 for the on-load voltage were provided by Listenbee, Jeong, and McCann (2014) using the small-scale VRFB. Our graph of the on-load voltage, using our mathematical model set at these experimental parameters, is shown in Figure 5 below.

Comparing Figures 4 and 5, the relative shapes of the curves with respect to time and the change in on-load voltage matched, validating the mathematical model based on the experimental data gathered from the partner institution. The load resistance and impedance, $\mu_4$ and $\mu_5$, of the actual battery were unknown due to difficulty in quantifying these parameters by the ASU researchers. However, for the model to be valid, these parameters were essential, as the level of resistance depends on the cell volume. Also, load resistance and battery impedance affects the efficiency of the VRFB. Therefore, $\mu_4$ and $\mu_5$ were adjusted until the graph (Figure 5) closely matched the experimental graph (Figure 4). The resulting values for $\mu_4$ and $\mu_5$ that validated the model were 5.5 mΩ for $\mu_4$ and 0.55 mΩ for $\mu_5$.

Design Method for VRFB

Once validated, the model was used to complete the fourth objective: determine the optimal design parameters to suit the energy needs of the household. Optimal was defined as the values of $\mu_1$ and $\mu_2$ that kept the on-load voltage from going below 0.80 V. This value was determined by analyzing equation (6), showing the no-load voltage that contains a natural log function of the vanadium ion concentration. If
the ion concentration decreased to a low value, the value of the equation (voltage) dropped off rapidly as demonstrated in Figure 4. Since inverters can only handle a certain range of voltage changes, these inverters cannot compensate for large voltage drops. Thus, the house would either not have electricity, or would have to rely on a traditional, nonrenewable electric grid to compensate for a large voltage drop within the battery. When the ion concentration was at 10% of the cell standard, the voltage of the battery was roughly 0.80 V.

With this value determining the required minimum on-load voltage, the cell and tank volumes were manipulated to determine how the values affected the on-load voltage. As $\mu_1$ and $\mu_2$ were increased, the on-load voltage graph was vertically transformed towards increasing voltage. Figure 6 shows this trend with the cell volume set at 100 L and the tank volume set at 900 L.

![Figure 6. On-load Voltage vs. Time with 100 L Cell](image1)

Likewise, as $\mu_1$ and $\mu_2$ were decreased, the graph was vertically shifted towards decreasing voltage. This trend is shown in Figure 7 with the cell and tank volumes set at 5.0 L and 45 L, respectively.

Since the size of the cell has a large impact on the overall cost of a VRFB due to the expensive ion-exchange membrane, the value for $\mu_1$ was picked based on the smallest value that it could be set to while keeping the resultant on-load voltage above 0.80 V throughout the entire 24-hour cycle. According to the graphs, any volume below 11.5 L resulted in a voltage drop of below 0.5 V, as shown in Figure 7. Therefore, the resulting value for the volume of the cell was 11.5 L. The tank volume, set at a 9:1 ratio to the cell, was found to be 103.7 L. As shown in Figure 8, these values kept the on-load voltage above 1.0 V for the entire 24-hour period. These values, equaling a total volume of 115.2 L, are practical for implementation into an actual residential setting.

![Figure 7. On-load Voltage vs. Time with 5 L cell](image2)

![Figure 8. On-Load Voltage of VRFB with Optimal Parameters](image3)

**Conclusions and Future Work**

Energy storage could be a solution to the problem of bridging the gap between energy demand and energy supply from intermittent sources of energy. Simulating the results of integrating energy storage technology, such as VRFBs, into various settings could help increase the use of renewable energy and make going “off-grid” a more feasible option. Beginning with data gathered from a PV array system and an actual home, this data was used to run
a mathematical model that simulated the behavior of a VRFB. This model produced graphs of the available on-load voltage over time. By analyzing these graphs, the minimum cell and tank volumes that would avoid significant voltage drops were determined.

Although the values for cell and tank volumes were relatively small, larger cell volumes correlated to smaller resistances due to the inverse relationship between cell surface area and resistance. Smaller resistances result in higher efficiencies, so there is a tradeoff between size and efficiency. Larger batteries are more efficient but more expensive as well. While the cell and tank volumes largely depend on the electrical load, which varies per scenario, the volumes could always be increased above the minimum total volume needed to increase the battery’s efficiency, depending on how much a consumer or company is willing to spend.

Since the experimental data for the on-load voltage matched our theoretical data, the model was validated. Using this validated model, future researchers could characterize the scaled up or scaled down behavior of vanadium redox batteries of any size. Also, by using a different current input, the model could predict the behavior of VRFBs in numerous settings, such as a hospital, university, or factory, which have widely varying energy loads. The next step in future research would be to actually construct a battery based on the parameters from the model and implement its technology into a home with alternative energy sources.

References


